FINAL REPORT FOR 2008
VIRGINIA - CHESAPEAKE BAY FINFISH AGEING

by

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Final Report

Finfish Ageing for Virginia Catches and
Application of Virtual Population Analysis to
Provide Management Advice

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Executive Summary

In this report we present the ageing results of 14 finfish species collected from commercial and recreational catches made in the Chesapeake Bay and Virginia waters of Atlantic, U.S.A. in 2008. All fish were collected by the Virginia Marine Resources Commission's (VMRC) Stock Assessment Program and the Center for Quantitative Fisheries Ecology (CQFE) at Old Dominion University in 2008 and aged in 2009 at Ageing Laboratory of CQFE. This report is broken down into chapters, one for each of the 14 species we aged. For each species, we present measures of ageing precision, graphs of year-class distributions, and age-length keys. In addition, in Chapter 14 we summarize the results of our research on sheepshead (*Archosargus probatocephalus*) population dynamics in the Chesapeake Bay of Virginia between 2006 and 2008, including sheepshead data collection, growth, reproductive status, and recommendations for its management.

Three calcified structures (hard-parts) are used to age the species. Specifically, two calcified structures were used for determining fish ages of the following three species: striped bass, *Morone saxatilis*, (n = 1132); summer flounder, *Paralichthys dentatus*, (n = 765); and tautog, *Tautoga onitis*, (n = 134). Scales and otoliths were used to age summer flounder and striped bass, opercula and otoliths were used to age tautog. Comparing alternative hard-parts allowed us to assess their usefulness in determining fish age as well as the relative precision of each structure. Ages were determined from otoliths only for the following species: Atlantic croaker, *Micropogonias undulatus*, (n = 546); black drum, *Pogonias cromis*, (n = 233); bluefish, *Pomatomus saltatrix*, (n = 320); cobia, *Rachycentron canadum*, (n = 52); red drum, *Sciaenops ocellatus*, (n = 64); spadefish, *Chaetodipterus faber*, (n = 313); Spanish mackerel, *Scomberomorous maculates*, (n = 242); Sheepshead (n = 167); spot, *Leiostomus xanthurus*, (n = 205); spotted seatrout, *Cynoscion nebulosus*, (n = 231); and weakfish, *Cynoscion regalis*, (n = 366). In total, we made 10,628 age readings from scales, otoliths and opercula collected during 2008. A summary of the age ranges for all species aged is presented in Table I.

In this report, we also present sample sizes and coefficient of variation (CV) for estimates of age composition for the following species: Atlantic croaker, bluefish, spadefish, Spanish mackerel, spot, spotted seatrout, striped bass, summer flounder, tautog, and weakfish. The sample sizes and the CVs enabled us to determine how many fish we needed to age in each length interval and to measure the precision for estimates of major age classes in each species, respectively, enhancing our efficiency and effectiveness on ageing those species.

As part of our continued public outreach focused in marine fisheries biology and management, we participated in the Sea Camp organized by the Department of Ocean, Earth, and Atmospheric Sciences at Old Dominion University during the summer of 2008. The Sea Camp is designed to educate middle and high school students about marine resources management and environmental protection. To support other environmental and wildlife agencies, and charities, we donated more than 1,658 pounds of dissected fish to Wildlife Response, Inc., a local wildlife rescue agency which is responsible for saving injured animals found by the public- and to the Salvation Army.

In 2008, we continued to upgrade our Age & Growth Laboratory website, which can be accessed at http://www.odu.edu/fish.The website includes an electronic version of this document and our previous VMRC final reports- from 1999 to 2007. The site also provides more detailed explanations of the methods and structures we use in age determination.

Table I. The minimum and maximum ages, number of fish and their hard-parts, number of fish, and age readings for the14 finfish species collected and aged in 2008. The hard-parts and age readings include both otoliths and scales for striped bass and summer flounder, and both otoliths and opercula for tautog.

Species	Number of fish collected	Number of hard-parts	Number of fish aged	Number of readings*	Minimum age	Maximum age
Atlantic Croaker	753	737	546	1092	1	16
Black Drum	233	233	233	466	0	56
Bluefish	412	412	320	640	0	11
Cobia	52	52	52	104	3	12
Red Drum	64	64	64	128	1	16
Sheepshead	167	167	167	334	1	35
Spadefish	384	383	313	626	0	13
Spanish Mackerel	260	260	242	484	0	9
Spotted seatrout	233	233	231	462	0	8
Spot	249	249	205	410	0	4
Striped Bass	1392	1664	1132	2780	3	22
Summer Flounder	911	1067	765	1844	0	10
Tautog	136	267	134	526	2	9
Weakfish	677	677	366	732	1	14
Totals	5923	6465	4770	10628		

* Age readings don't include those for the estimates of reader-self and time-series precision. Please see details in each chapter.

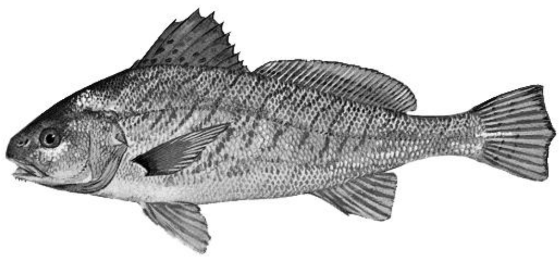
Acknowledgements

We thank Lakshmi Chaitanya, Sita Atchyutuni, Billy Culver, and James Davies for their technical expertise in preparing otoliths, scales, and opercula for age determination. They all put in long hours processing "tons" of fish in our lab. We are specifically thankful for Mr. James Davies editorial revision of the report and for Dr. William Persons' III hard work on our *Species Updates* and web page. A special note of appreciation is extended to Joe Grist and Joe Cimino and their technicians at the VMRC, including Richard Hancock, Myra Thompson, and Chris Williams for their many efforts in this cooperative project. We would like also to thank our Ph. D. students Joey Ballenger, Stacy Beharry, and Renee Reilly and post-doc Jason Schaffler for their help in processing fish whenever we were short of hands. Finally, we would like to thank the Virginia Coastal Conservation Association (VA CCA), Virginia Saltwater Recreational

Fishing Development Fund, local recreational anglers, angler clubs, and marinas for their efforts to make sheepshead collection possible.

The image on the front cover is an otolith thin-section from a 315 mm (12.4 inch) total length, 5 year-old male spot. The fifth annulus is forming at the edge of the otolith.

Chapter 1
Atlantic Croaker



Micropogonias undulatus

INTRODUCTION

We aged a total of 546 Atlantic croaker, *Micropogonias undulatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The croaker ages ranged from 1 to 16 years old with an average age of 6.6, and standard deviation of 2.4, and a standard error of 0.1. Fifteen age classes (1 to 14, and 16) were represented, comprising fish from the 1992, 1994 through 2006 year-classes. Fish from the 2001 year-class dominated the sample with 38%, followed by 2003 (13%) and 2002 (11%).

METHODS

Sample size for ageing — We estimated sample size for ageing croaker in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing croaker in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of croaker collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of croaker used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collections — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

Preparation — Sagittal otoliths (hereafter, referred to as "otoliths") were processed for age determination following the methods described in Barbieri et al. (1994) with a few modifications. The left or right otolith was randomly selected and attached, distal side down, to a glass slide with clear Crystalbond™ 509 adhesive. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section) was then removed from marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). Thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx® mounting medium that not only adhered the sections to the slide, but, more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-sections.

Readings - The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

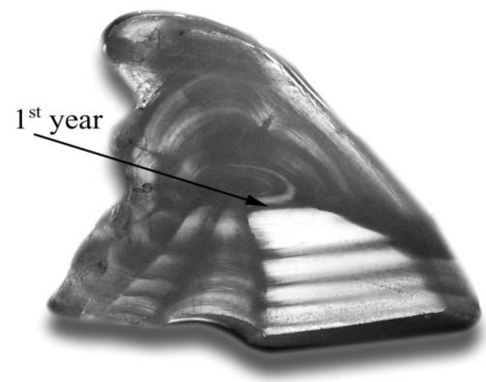
Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of annuli in the thin-section.

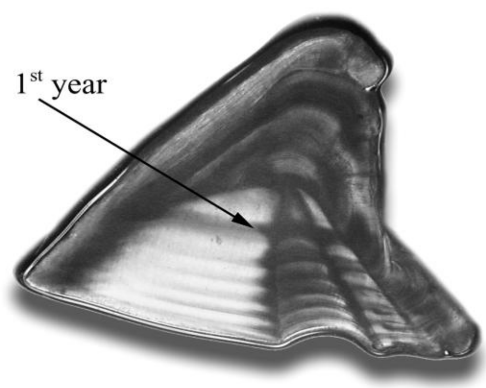
If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Atlantic croaker annulus formation occurs between the months of April and May (Barbieri et al. 1994). A croaker captured between January 1 and May 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification. Each reader aged all of the otolith samples. In addition to the CQFE system of ageing, the ageing criteria reported in Barbieri et al. (1994) were used in age determination, particularly regarding the location of the first annulus (Figure 1).



(a)



(b)

Figure 1. Otolith cross-sections of a) a 5 year old croaker with a small 1st annulus, and b) a 6 year old croaker with a large 1st annulus.

Due to discrepancy on identification of the first annulus of Atlantic croaker among Atlantic states, Atlantic States Marine Fisheries Commission (ASMFC) has decided not to count the smallest annulus at the center of the thin-section as the first annulus. Following ASMFC's instruction, we didn't count the smallest annulus at the center as the first annulus in 2008.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 533 for ageing Atlantic croaker in 2008, ranging in length interval from 7 to 25 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 9% for age 5 and 6 to the largest CV of 20% for age 2 fish. In 2008, we randomly selected and aged 546 fish from 736 croaker collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 20 fish. However, these were primarily from the very large length intervals (Table 1), therefore, the precision for the estimates of major age groups (from age 4 to 8) would not be influenced significantly.

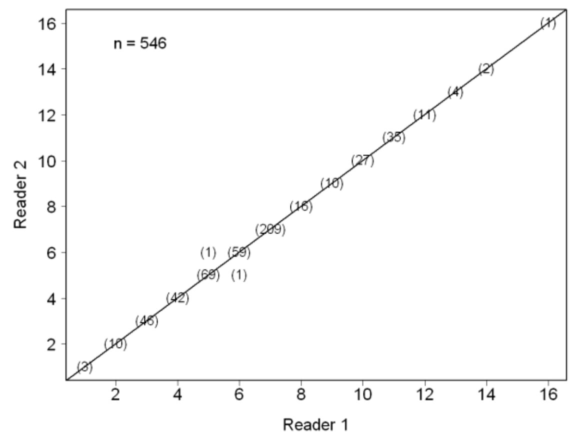


Figure 2. Between-reader comparison of otolith age estimates for Atlantic croaker collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

The measurement of reader self-precision was very high for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV = 0.3% (test of symmetry: $\chi^2 = 2$, df = 2, P = 0.3679). There is 100% agreement between the first and second readings for Reader 2. There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 99.6% and a CV of smaller than 0.05% (Figure 2).

There is no time-series bias for both readers. Reader 1 had an agreement of 98% with ages of fish aged in 2003 with a CV of 1% (test of symmetry: $\chi^2 = 1$, df = 1, P = 0.3173). Reader 2 had an agreement of 100% with ages of fish aged in 2003.

Of the 546 fish aged with otoliths, 15 age classes (1 to 14, 16) were represented (Table 2). The average age was 6.6 years, and the standard deviation and standard error were 2.4 and 0.1, respectively.

Year-class data show that the fishery was comprised of 15 year-classes: fish from the 1992, 1993-2007 year-classes, with fish primarily from the 2001 year-class (38%). The ratio of males to females was 1:2.15 in the sample collected (Figure 3).

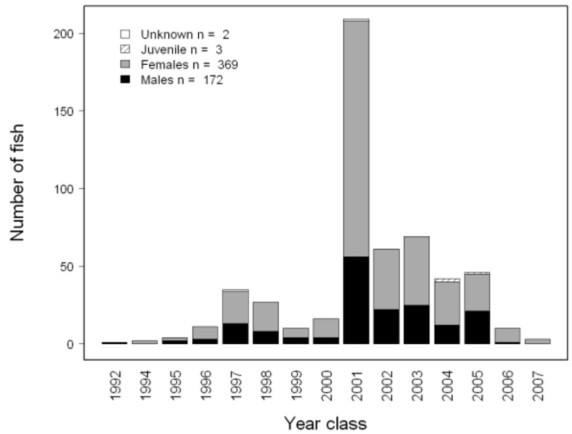


Figure 3. Year-class frequency distribution for Atlantic croaker collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We developed an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Barbieri, L.R., M.E. Chittenden, and C.M. Jones. 1994. Age, growth, and mortality of Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay region, with a discussion of the apparent geographical changes in population dynamics. Fish. Bull. 92:1-12.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of Atlantic croaker collected and aged in each 1-inch length interval in 2008. "Target" represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7 - 7.99	5	5	5	0
8 - 8.99	5	42	13	0
9 - 9.99	21	40	21	0
10 - 10.99	35	51	34	1
11 - 11.99	54	79	53	1
12 - 12.99	102	142	108	0
13 - 13.99	82	121	86	0
14 - 14.99	69	82	67	2
15 - 15.99	56	69	56	0
16 - 16.99	42	46	44	0
17 - 17.99	28	41	41	0
18 - 18.99	13	11	11	2
19 - 19.99	6	6	6	0
20 - 20.99	5	1	1	4
21 - 21.99	5	0	0	5
25 - 25.99	5	0	0	5
Totals	533	736	546	20

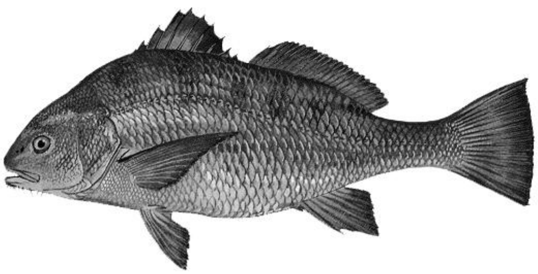
Table 2. The number of Atlantic croaker assigned to each total length-at-age category for 546 fish sampled for otolith age determination in Virginia during 2008

	Age														
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**Totals**
7 - 7.99	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	5
8 - 8.99	0	1	4	3	2	0	3	0	0	0	0	0	0	0	0	13
9 - 9.99	0	6	5	3	5	0	1	0	0	0	1	0	0	0	0	21
10 - 10.99	0	1	10	9	6	3	3	0	0	0	2	0	0	0	0	34
11 - 11.99	0	1	8	12	15	7	7	1	0	0	2	0	0	0	0	53
12 - 12.99	0	0	8	8	20	20	37	0	2	5	6	1	1	0	0	108
13 - 13.99	0	0	1	2	11	9	48	3	2	5	3	1	1	0	0	86
14 - 14.99	0	0	2	1	6	11	34	2	0	5	5	1	0	0	0	67
15 - 15.99	0	0	2	3	2	6	31	4	0	2	3	2	1	0	0	56
16 - 16.99	0	0	3	0	0	3	21	5	2	3	4	3	0	0	0	44
17 - 17.99	0	0	3	0	1	1	17	1	3	6	4	2	1	2	0	41
18 - 18.99	0	0	0	0	0	0	5	0	1	1	3	1	0	0	0	11
19 - 19.99	0	0	0	0	1	1	1	0	0	0	2	0	0	0	1	6
20 - 20.99	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Totals	3	10	46	42	69	61	209	16	10	27	35	11	4	2	1	546

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Atlantic croaker sampled for age determination in Virginia during 2008

	Age														
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**
7 - 7.99	0.6	0.2	0	0.2	0	0	0	0	0	0	0	0	0	0	0
8 - 8.99	0	0.077	0.308	0.231	0.154	0	0.231	0	0	0	0	0	0	0	0
9 - 9.99	0	0.286	0.238	0.143	0.238	0	0.048	0	0	0	0.048	0	0	0	0
10 - 10.99	0	0.029	0.294	0.265	0.176	0.088	0.088	0	0	0	0.059	0	0	0	0
11 - 11.99	0	0.019	0.151	0.226	0.283	0.132	0.132	0.019	0	0	0.038	0	0	0	0
12 - 12.99	0	0	0.074	0.074	0.185	0.185	0.343	0	0.019	0.046	0.056	0.009	0.009	0	0
13 - 13.99	0	0	0.012	0.023	0.128	0.105	0.558	0.035	0.023	0.058	0.035	0.012	0.012	0	0
14 - 14.99	0	0	0.03	0.015	0.09	0.164	0.507	0.03	0	0.075	0.075	0.015	0	0	0
15 - 15.99	0	0	0.036	0.054	0.036	0.107	0.554	0.071	0	0.036	0.054	0.036	0.018	0	0
16 - 16.99	0	0	0.068	0	0	0.068	0.477	0.114	0.045	0.068	0.091	0.068	0	0	0
17 - 17.99	0	0	0.073	0	0.024	0.024	0.415	0.024	0.073	0.146	0.098	0.049	0.024	0.049	0
18 - 18.99	0	0	0	0	0	0	0.455	0	0.091	0.091	0.273	0.091	0	0	0
19 - 19.99	0	0	0	0	0.167	0.167	0.167	0	0	0	0.333	0	0	0	0.167
20 - 20.99	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Chapter 2
Black Drum



Pogonias cromis

INTRODUCTION

A total of 233 black drum, *Pogonias cromis*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The average age of the sample was 28 years, with a standard deviation of 14.9 and a standard error of 0.98. Forty-nine age classes were represented with the youngest age of 0 and the oldest age of 56 years, comprising fish from the earliest year-class of 1952 to the most recent year-class of 2008.

METHODS

Handling of collection — Sagittal Otoliths (hereafter, refer to as "otoliths") were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

Preparation — Otoliths were processed for age determination following the methods described in Bobko (1991) and Jones and Wells (1998). The left or right sagittal otolith was randomly selected and attached, distal side down, to a glass slide with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three inch diameter, Norton® Diamond Grinding Wheels, separated by a stainless steel spacer of 0.4mm (diameter 2.5"). The position of the marked core fell within the 0.4mm space between the blades, such that the core was included in the thin-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx® mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the dark band deposition period, is interpreted as being toward the next age class.

For example, black drum otolith deposition occurs from May through June (Beckman et al. 1990; Jones and Wells 1997). A black drum captured between January 1 and June 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1). Each reader aged all of the otolith samples.

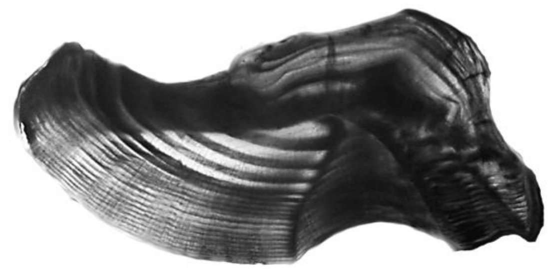


Figure 1. Otolith thin-section from a 20 year-old black drum.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

The measurement of reader self-precision was very high for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV = 0.6% and an agreement of 80% (test of symmetry: $\chi^2 = 10$, df = 10, P = 0.4405). There is no significant difference between the first and second readings for Reader 2 with a CV = 0.6% and an agreement of 74% (test of symmetry: $\chi^2 = 10.33$, df = 11, P = 0.5007). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 82.4% and a CV of 0.5% (test of symmetry: $\chi^2 = 34.33$, df = 28, P = 0.1901) (Figure 2).

Reader 1 had an agreement of 72% with ages of fish aged in 2000 with a CV of 0.7% (test of symmetry: $\chi^2 = 12$, df = 13, P = 0.5276). Reader 2 had an agreement of 72% with ages of fish aged in 2000 with a CV of 1.6% (test of symmetry: $\chi^2 = 14$, df = 12, P = 0.3007).

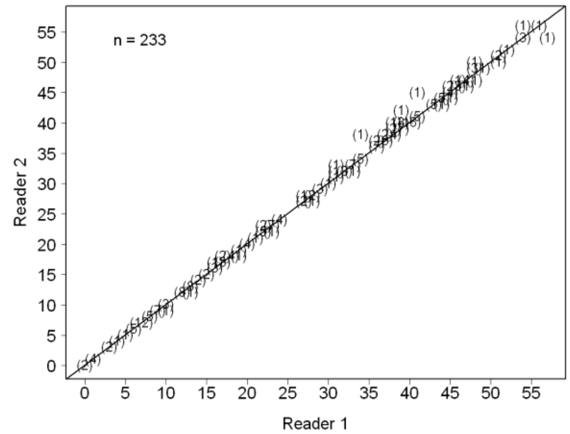


Figure 2. Between-reader comparison of otolith age estimates for black drum collected in Chespakead Bay and Virginia waters of Atlantic in 2008.

Of the 233 fish aged with otoliths, 49 age classes were represented (Table 1). The average age of the sample was 28 years, with a standard deviation of 14.9 and a standard error of 0.98. The youngest fish was a 0 year old and the oldest fish was 56 years old, representing the year-classes as early as 1952 and as late as 2008 (Figure 3).

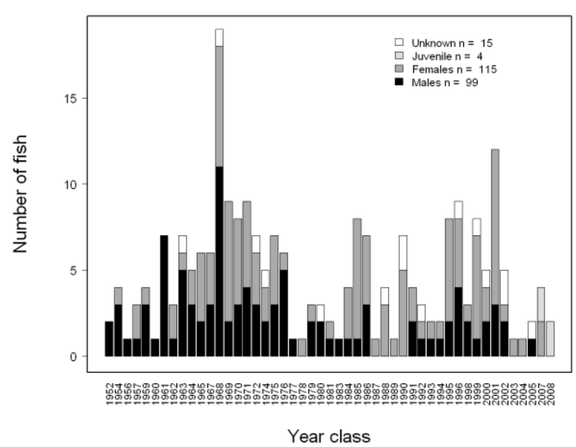


Figure 3. Year-class frequency distribution for black drum collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Beckman, D. W., C. A. Wilson, and A. L. Stanley. 1990. Age and growth of black drum in Louisiana waters of the Gulf of Mexico. Transactions of American Fisheries Society 19:537-544.

Bobko, S. J. 1991. Age, growth, and reproduction of black drum, *Pogonias cromis*, in Virginia. M.S. thesis. Old Dominion University, Norfolk, VA.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age eterminations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Jones, C.J. 1998. Report on black drum studies for the period 1990-1996. study of important recreational fishes in the Chesapeake Bay. Federal Aid in Sport Fish Restoration Act project F-88-R-3.

Jones, C.J. and B.K. Wells. 1998. Age, growth, and mortality of black drum, *Pogonias cromis*, in the Chesapeake Bay region. Fish. Bull. 96:451-461.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. The number of black drum assigned to each total length (inch)-at-age category for 233 fish sampled for otolith age determination in Virginia during 2008.

Interval	Age																							
	0	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**27**
7 - 7.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 - 8.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 16.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 - 18.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0	0	0	1	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 36.99	0	0	0	0	0	0	2	1	2	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0
37 - 37.99	0	0	0	0	0	0	0	0	0	2	2	3	0	0	0	0	0	0	1	0	0	0	0	0	0
38 - 38.99	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	0	1	0	1	0	0	0	0	0	0
39 - 39.99	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	1	0	1	0	0	0	0	0	0
40 - 40.99	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	1	1	0	0	1	0	0	0	0
41 - 41.99	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	2	2	0	0	0
42 - 42.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	2	1	0	0
43 - 43.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0	1	0	2	0	0
44 - 44.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	1
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53 - 53.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	2	4	2	1	1	5	12	5	8	3	9	8	2	2	3	4	7	1	4	1	7	8	4	1	2

Table 1. (continued)

Interval	Age																							
	28	**29**	**30**	**31**	**32**	**33**	**34**	**36**	**37**	**38**	**39**	**40**	**41**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**51**	**52**	**54**	**56**	**Totals**
7 - 7.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
8 - 8.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16 - 16.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18 - 18.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19 - 19.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
20 - 20.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
22 - 22.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
23 - 23.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
29 - 29.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
31 - 31.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
32 - 32.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
33 - 33.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
34 - 34.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
35 - 35.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
36 - 36.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10
37 - 37.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
38 - 38.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
39 - 39.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
40 - 40.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
41 - 41.99	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	10
42 - 42.99	1	0	0	0	0	2	1	0	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	15
43 - 43.99	0	1	0	0	0	1	1	2	0	1	3	1	0	1	0	1	0	0	0	0	0	0	0	0	19
44 - 44.99	0	1	0	0	1	0	0	2	2	0	1	0	1	1	0	0	1	0	0	0	0	0	1	0	14
45 - 45.99	0	1	0	1	1	1	1	0	0	2	3	4	0	0	1	0	0	0	1	1	0	0	0	0	22
46 - 46.99	1	0	0	0	0	1		1	1	1	1	2	1	1	1	2	0	0	0	0	0	0	0	1	17
47 - 47.99	0	0	0	0	2	0	1	0	2	3	1	4	1	0	2	0	1	2	0	1	0	0	1	0	21
48 - 48.99	0	0	1	0	1	0	0	0	1	0	0	6	1	2	0	3	1	1	0	0	0	0	1	1	20
49 - 49.99	0	0	0	0	1	1	0	1	1	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	9
50 - 50.99	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	5
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	3
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
53 - 53.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Totals	3	3	1	1	6	7	5	7	9	8	9	19	6	6	5	7	3	7	1	4	3	1	4	2	233

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for black drum sampled for age determination in Virginia during 2008.

Interval	Age																
	0	1	3	4	5	6	7	8	9	10	12	13	14	15	16	17	18
7 - 7.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 - 8.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 16.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 - 18.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0	0	0	0.167	0.667	0	0.167	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0	0.143	0.429	0.143	0.286	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0	0	0.5	0	0.25	0	0.25	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0	0.4	0.4	0	0	0.2	0	0	0	0	0
36 - 36.99	0	0	0	0	0	0	0.2	0.1	0.2	0	0.3	0	0	0	0	0	0
37 - 37.99	0	0	0	0	0	0	0	0	0	0.25	0.25	0.375	0	0	0	0	0
38 - 38.99	0	0	0	0	0	0	0	0	0	0.167	0	0	0.333	0	0.167	0	0.167
39 - 39.99	0	0	0	0	0	0	0	0	0	0	0.375	0.125	0	0.125	0.125	0	0.125
40 - 40.99	0	0	0	0	0	0	0	0	0	0	0	0.286	0	0	0	0.286	0.143
41 - 41.99	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1
42 - 42.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
43 - 43.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.053	0.105	0
44 - 44.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0.045	0	0	0
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53 - 53.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

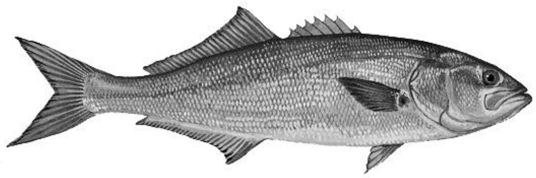
Table 2. (continued)

Interval	Age														
	19	**20**	**21**	**22**	**23**	**24**	**25**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**36**
7 - 7.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 - 8.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 16.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 - 18.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 36.99	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
37 - 37.99	0	0.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 - 38.99	0	0.167	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 - 39.99	0	0.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 - 40.99	0.143	0	0	0.143	0	0	0	0	0	0	0	0	0	0	0	0
41 - 41.99	0	0	0	0.2	0.2	0	0	0	0.1	0	0	0	0	0.1	0	0
42 - 42.99	0	0	0	0.067	0.133	0.067	0	0	0.067	0	0	0	0	0.133	0.067	0
43 - 43.99	0	0.053	0	0.053	0	0.105	0	0	0	0.053	0	0	0	0.053	0.053	0.105
44 - 44.99	0	0	0	0.143	0	0.071	0	0	0	0.071	0	0	0.071	0	0	0.143
45 - 45.99	0	0	0	0	0.136	0	0	0.045	0	0.045	0	0.045	0.045	0.045	0.045	0
46 - 46.99	0	0	0	0	0.059	0	0.059	0	0.059	0	0	0	0	0.059	0.059	0.059
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0.095	0	0.048	0
48 - 48.99	0	0	0	0	0	0	0	0.05	0	0	0.05	0	0.05	0	0	0
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0.111	0.111	0	0.111
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53 - 53.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

Interval	Age														
	37	**38**	**39**	**40**	**41**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**51**	**52**	**54**	**56**
7 - 7.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 - 8.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 16.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 - 18.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 36.99	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
37 - 37.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 - 38.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 - 39.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 - 40.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 - 41.99	0	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
42 - 42.99	0.133	0	0	0.067	0.067	0	0	0	0	0	0	0	0	0	0	0
43 - 43.99	0	0.053	0.16	0.053	0	0.053	0	0.053	0	0	0	0	0	0	0	0
44 - 44.99	0.143	0	0.07	0	0.071	0.071	0	0	0.071	0	0	0	0	0	0.071	0
45 - 45.99	0	0.091	0.14	0.182	0	0	0.045	0	0	0	0.045	0.045	0	0	0	0
46 - 46.99	0.059	0.059	0.06	0.118	0.059	0.059	0.059	0.118	0	0	0	0	0	0	0	0.059
47 - 47.99	0.095	0.143	0.05	0.19	0.048	0	0.095	0	0.048	0.095	0	0.048	0	0	0.048	0
48 - 48.99	0.05	0	0	0.3	0.05	0.1	0	0.15	0.05	0.05	0	0	0	0	0.05	0.05
49 - 49.99	0.111	0	0	0	0.111	0.111	0	0.111	0	0.111	0	0	0.111	0	0	0
50 - 50.99	0	0	0	0	0	0	0	0	0	0.4	0	0	0.2	0.2	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0.333	0	0.667	0	0	0	0
52 - 52.99	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
53 - 53.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Chapter 3
Bluefish



Pomatomus saltatrix

INTRODUCTION

We aged a total of 320 bluefish, *Pomatomus saltatrix*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The bluefish ages ranged from 0 to 11 years old with an average age of 2.6, and standard deviation of 2.2, and a standard error of 0.12. Twelve age classes represented fish from the 1997 to 2008 year-classes. Fish from the 2006 year-class dominated the sample with 53%, followed by 2007 (23%).

METHODS

Sample size for ageing — We estimated sample size for ageing bluefish in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing bluefish in 2008; θ_a stands for the proportion of age *a* fish in a catch. V_a and B_a represent variance components within and between length intervals for age *a*, respectively; *CV* is coefficient of variance; *L* is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and *CV* were calculated using pooled age-length data of bluefish collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. *L* was the total number of bluefish used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age *A* (number) of fish is that *A* should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collections — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

Preparation — We used our thin-section and bake technique to process bluefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each otolith was mounted with clear, Crystalbond™ 509 adhesive onto a standard microscope slide with its distal surface orientated upwards. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as “thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as “blades”), separated by a stainless steel spacer of 0.4 mm (diameter 2.5”). The otolith was positioned so that the blades straddled each side of the otolith focus marked by pencil. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in “broadening” and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the thin-section was placed into a ceramic “Coors” spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was dependent on thin-section’s size and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx® mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces “x” in our notation, and is the initial “age” assignment of the fish.

Second, the otolith thin-section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called “even” and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being counted toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a “+” is added to the notation.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called “even” and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a “+” is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species specific annulus deposition period and before January 1, it is assigned an age class notation of “x + x”, where “x” is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the dark band deposition period, is interpreted as being toward the next age class.

For example, bluefish otolith deposition occurs March through May (Robillard et al. in press). A bluefish captured between January 1 and May 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

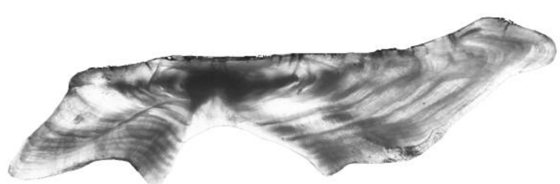


Figure 1. Otolith thin-section from a 8 year-old female bluefish with a total length of 850 mm.

If an otolith was properly sectioned the sulcal groove came to a sharp point within the middle of the focus. Typically the first year's annulus was found by locating the focus of the otolith, which was characterized as a visually distinct dark, oblong region found in the center of the otolith. The first year's annulus had the highest visibility proximal to the focus along the edge of the sulcal groove. Once located, the first year's annulus was followed outward from the sulcal groove towards the dorsal perimeter of the otolith. Often, but not always, the first year was associated with a very distinct crenellation on the dorsal surface and a prominent protrusion on the ventral surface. Unfortunately, both of these landmarks had a tendency to become less prominent in older fish.

Even with the bake and thin-section technique, interpretation of the growth zones from the otoliths of young bluefish was difficult. Rapid growth within the first year of life prevents a sharp delineation between opaque and translucent zones. When the exact location of the first year was not clearly evident, and the otolith had been sectioned accurately, a combination of surface landscape (1st year crenellation) and the position of the second annuli were used to help determine the position of the first annulus.

What appeared to be "double annuli" were occasionally observed in bluefish 4-7years of age and older. This double-annulus formation was typically characterized by distinct and separate annuli in extremely close proximity to each other. We do not know if the formation of these double annuli were two separate annuli, or in fact only one, but they seemed to occur during times of reduced growth after maturation. "Double annuli" were considered to be one annulus when both marks joined to form a central origin (the origin being the sulcal groove and the outer peripheral edge of the otolith). If these annuli did not meet to form a central origin they were considered two distinct annuli, and were counted as such.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 318 for ageing bluefish in 2008, ranging in length interval from 6 to 38 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 6% for age 2 and the largest CV of 23% for age 6 fish. In 2008, we randomly selected and aged 320 fish from the 410 bluefish collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 35 fish. Because those fish mainly fell within the very large and small length intervals (Table 1), the precision for the estimates of major age groups would not be influenced significantly.

The measurement of reader self-precision was very good for both Reader 1 (CV = 2.8%) and Reader 2 (CV = 1.5%), much better than in 2007 (Reader 1 CV = 3.8% and Reader 2 CV = 15.1%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 21.29$, df = 13, P = 0.0675), whereas, there was evidence of systematic disagreement between two readers in 2007 ($P < 0.0001$). The between-reader agreement for otoliths was 90.6% in 2008, much higher than in 2007 (The between-reader agreement for otoliths for one year or less was 94% of all aged fish in 2007) (Figure 2). Such a high agreement between the readers was due to the high quality of bluefish otolith thin-sections and experienced readers.

There is no time-series bias for both readers. Reader 1 had an agreement of 86% with ages of fish aged in 2000 with a CV of 11.5% (test of symmetry: $\chi^2 = 7$, df = 3, P = 0.0719). Reader 2 had an agreement of 96% with ages of fish aged in 2000 with a CV of 1.5% (test of symmetry: $\chi^2 = 2$, df = 2, P = 0.3679).

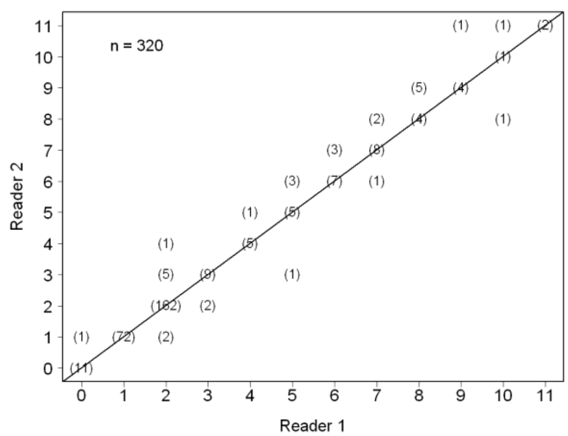


Figure 2. Between-reader comparison of otolith age estimates for bluefish collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 320 fish aged, 12 age classes were represented (Table 2). The average age for the sample was 2.6 years, and the standard deviation and standard error were 2.2 and 0.12, respectively.

Year-class data indicates that recruitment into the fishery began at age 0, which corresponded to the 2008 year-class for bluefish caught in 2008. One and two-year-old fish were the dominant year-classes in the 2008 sample (Figure 3).

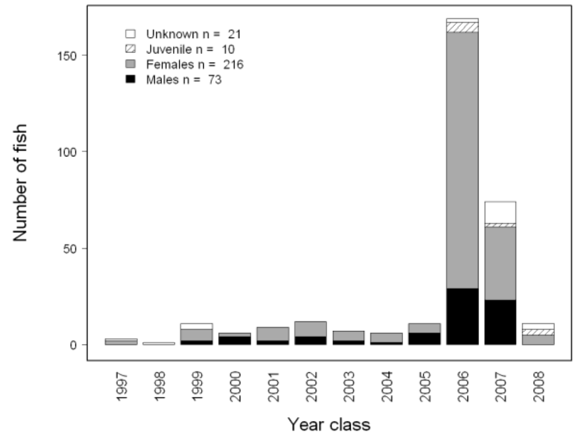


Figure 3. Year-class frequency distribution for bluefish collected for ageing in 2008. Distribution is broken down by sex. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

Robillard, E. M., C. S. Reiss, and C. M. Jones. 2009. Age-validation and growth of bluefish (*Pomatomus saltator*) along the East Coast of the United States. Fishereis Research 95:65-75.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of bluefish collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
6 - 6.99	5	1	1	4
7 - 7.99	5	0	0	5
8 - 8.99	5	7	5	0
9 - 9.99	5	16	14	0
10 - 10.99	5	13	12	0
11 - 11.99	8	15	9	0
12 - 12.99	18	25	19	0
13 - 13.99	22	26	21	1
14 - 14.99	29	37	30	0
15 - 15.99	27	44	27	0
16 - 16.99	24	37	24	0
17 - 17.99	26	36	26	0
18 - 18.99	24	38	27	0
19 - 19.99	13	15	13	0
20 - 20.99	8	9	8	0
21 - 21.99	5	6	5	0
22 - 22.99	5	7	6	0
23 - 23.99	5	9	7	0
24 - 24.99	5	10	7	0
25 - 25.99	5	2	2	3
26 - 26.99	5	1	1	4
27 - 27.99	5	1	1	4
28 - 28.99	5	7	7	0
29 - 29.99	6	5	5	1
30 - 30.99	7	11	11	0
31 - 31.99	6	7	7	0
32 - 32.99	5	7	7	0
33 - 33.99	5	6	6	0
34 - 34.99	5	2	2	3
35 - 35.99	5	3	3	2
36 - 36.99	5	5	5	0
37 - 37.99	5	2	2	3
38 - 38.99	5	0	0	5
Totals	318	410	320	35

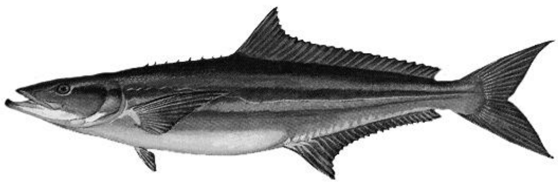
Table 2. The number of bluefish assigned to each total length-at-age category for 320 fish sampled for otolith age determination in Virginia during 2008.

	Age												
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Totals**
6 - 6.99	0	0	1	0	0	0	0	0	0	0	0	0	1
8 - 8.99	3	2	0	0	0	0	0	0	0	0	0	0	5
9 - 9.99	4	9	1	0	0	0	0	0	0	0	0	0	14
10 - 10.99	1	11	0	0	0	0	0	0	0	0	0	0	12
11 - 11.99	0	9	0	0	0	0	0	0	0	0	0	0	9
12 - 12.99	1	15	2	1	0	0	0	0	0	0	0	0	19
13 - 13.99	1	14	6	0	0	0	0	0	0	0	0	0	21
14 - 14.99	1	7	22	0	0	0	0	0	0	0	0	0	30
15 - 15.99	0	0	26	1	0	0	0	0	0	0	0	0	27
16 - 16.99	0	0	24	0	0	0	0	0	0	0	0	0	24
17 - 17.99	0	0	24	2	0	0	0	0	0	0	0	0	26
18 - 18.99	0	0	26	1	0	0	0	0	0	0	0	0	27
19 - 19.99	0	0	11	2	0	0	0	0	0	0	0	0	13
20 - 20.99	0	2	6	0	0	0	0	0	0	0	0	0	8
21 - 21.99	0	3	1	1	0	0	0	0	0	0	0	0	5
22 - 22.99	0	2	3	1	0	0	0	0	0	0	0	0	6
23 - 23.99	0	0	7	0	0	0	0	0	0	0	0	0	7
24 - 24.99	0	0	6	1	0	0	0	0	0	0	0	0	7
25 - 25.99	0	0	1	0	1	0	0	0	0	0	0	0	2
26 - 26.99	0	0	1	0	0	0	0	0	0	0	0	0	1
27 - 27.99	0	0	1	0	0	0	0	0	0	0	0	0	1
28 - 28.99	0	0	0	0	2	4	1	0	0	0	0	0	7
29 - 29.99	0	0	0	1	2	1	0	1	0	0	0	0	5
30 - 30.99	0	0	0	0	1	1	5	2	2	0	0	0	11
31 - 31.99	0	0	0	0	0	1	1	2	1	2	0	0	7
32 - 32.99	0	0	0	0	0	0	3	2	1	1	0	0	7
33 - 33.99	0	0	0	0	0	0	2	1	2	1	0	0	6
34 - 34.99	0	0	0	0	0	0	0	1	0	1	0	0	2
35 - 35.99	0	0	0	0	0	0	0	0	0	3	0	0	3
36 - 36.99	0	0	0	0	0	0	0	0	0	2	1	2	5
37 - 37.99	0	0	0	0	0	0	0	0	0	1	0	1	2
Totals	11	74	169	11	6	7	12	9	6	11	1	3	320

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for bluefish sampled for age determination in Virginia during 2008.

	Age											
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
6 - 6.99	0	0	1	0	0	0	0	0	0	0	0	0
8 - 8.99	0.6	0.4	0	0	0	0	0	0	0	0	0	0
9 - 9.99	0.286	0.643	0.071	0	0	0	0	0	0	0	0	0
10 - 10.99	0.083	0.917	0	0	0	0	0	0	0	0	0	0
11 - 11.99	0	1	0	0	0	0	0	0	0	0	0	0
12 - 12.99	0.053	0.789	0.105	0.053	0	0	0	0	0	0	0	0
13 - 13.99	0.048	0.667	0.286	0	0	0	0	0	0	0	0	0
14 - 14.99	0.033	0.233	0.733	0	0	0	0	0	0	0	0	0
15 - 15.99	0	0	0.963	0.037	0	0	0	0	0	0	0	0
16 - 16.99	0	0	1	0	0	0	0	0	0	0	0	0
17 - 17.99	0	0	0.923	0.077	0	0	0	0	0	0	0	0
18 - 18.99	0	0	0.963	0.037	0	0	0	0	0	0	0	0
19 - 19.99	0	0	0.846	0.154	0	0	0	0	0	0	0	0
20 - 20.99	0	0.25	0.75	0	0	0	0	0	0	0	0	0
21 - 21.99	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0
22 - 22.99	0	0.333	0.5	0.167	0	0	0	0	0	0	0	0
23 - 23.99	0	0	1	0	0	0	0	0	0	0	0	0
24 - 24.99	0	0	0.857	0.143	0	0	0	0	0	0	0	0
25 - 25.99	0	0	0.5	0	0.5	0	0	0	0	0	0	0
26 - 26.99	0	0	1	0	0	0	0	0	0	0	0	0
27 - 27.99	0	0	1	0	0	0	0	0	0	0	0	0
28 - 28.99	0	0	0	0	0.286	0.571	0.143	0	0	0	0	0
29 - 29.99	0	0	0	0.2	0.4	0.2	0	0.2	0	0	0	0
30 - 30.99	0	0	0	0	0.091	0.091	0.455	0.182	0.182	0	0	0
31 - 31.99	0	0	0	0	0	0.143	0.143	0.286	0.143	0.286	0	0
32 - 32.99	0	0	0	0	0	0	0.429	0.286	0.143	0.143	0	0
33 - 33.99	0	0	0	0	0	0	0.333	0.167	0.333	0.167	0	0
34 - 34.99	0	0	0	0	0	0	0	0.5	0	0.5	0	0
35 - 35.99	0	0	0	0	0	0	0	0	0	1	0	0
36 - 36.99	0	0	0	0	0	0	0	0	0	0.4	0.2	0.4
37 - 37.99	0	0	0	0	0	0	0	0	0	0.5	0	0.5

Chapter 4
Cobia



Rachycentron canadum

INTRODUCTION

A total of 52 cobia, *Rachycentron canadum*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The average age of the sample was 5.6 years, with a standard deviation of 2.4 and a standard error of 0.33. Eight age classes were represented with the youngest age of 3 and the oldest age of 12 years, comprising fish from the earliest year-class of 1996 to the most recent year-class of 2005. The year class of 2004 was dominant in the sample (33%).

METHODS

Handling of collection — Sagittal Otoliths (hereafter, referred to as "otoliths") were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory identification numbers. All otoliths were stored inside of protective Axygen 2.0ml microtubes within their original labeled coin envelopes.

Preparation — Due to their fragility, we used our embedding and thin-sectioning method to prepare cobia otoliths for age determination. To start, a series of 14 mm x 5 mm x 3 mm wells (Ladd Industries silicon rubber mold) were pre-filled to half-volume with Loctite® 349 adhesive and permitted to cure for 24 hours until solidified. Otoliths were placed distal-side up on the solidified base layer. The remaining volume in the well was filled with Loctite® 349. When all the wells were filled, and no bubbles remained within the wells, the silicon rubber mold was placed under a UV light to solidify overnight. Once dry, each embedded otolith was removed from the mold and mounted with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using an Ultra-Fine Point Sharpie® permanent marker. At least one transverse cross-section (hereafter "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three inch diameter, Norton® Diamond Grinding Wheels (hereafter, "blades"), separated by a stainless steel spacer of 0.4mm (diameter 2.5"). The position of the marked core fell within the 0.4mm space between the blades, such that the core was included in the thin-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx® mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, cobia otolith deposition occurs during June (Franks et al. 1999). A cobia captured between January 1 and June 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

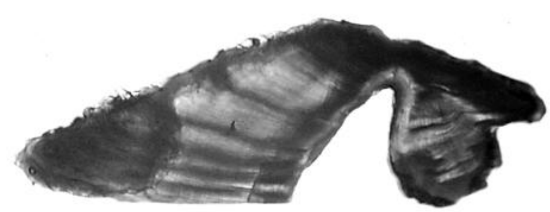


Figure 1. Otolith thin-section from a 1524 mm TL 6 year old cobia.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

The measurement of reader self-precision was very high for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV = 1.2% and an agreement of 92% (test of symmetry: $\chi^2 = 4$, df = 3, $P = 0.2615$). There is no significant difference between the first and second readings for Reader 2 with a CV = 1.2% and an agreement of 90% (test of symmetry: $\chi^2 = 5$, df = 5, $P = 0.4159$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 94.2% and a CV of 0.6% (test of symmetry: $\chi^2 = 3$, df = 3, $P = 0.3916$) (Figure 2).

Reader 1 had an agreement of 84% with ages of fish aged in 2000 with a CV of 1.5% (test of symmetry: $\chi^2 = 8$, df = 7, $P = 0.3326$). Reader 2 had an agreement of 84% with ages of fish aged in 2000 with a CV of 1.8% (test of symmetry: $\chi^2 = 6$, df = 6, $P = 0.4232$).

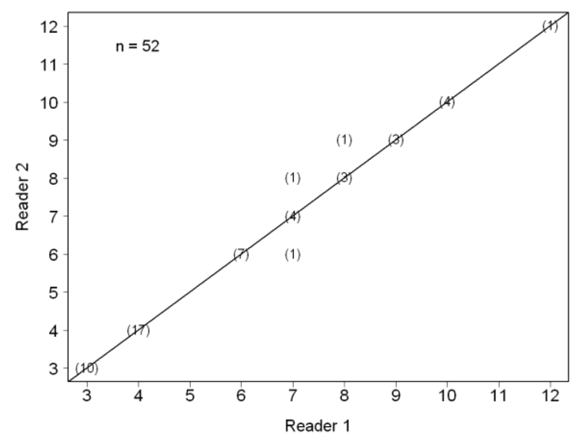


Figure 2. Between-reader comparison of otolith age estimates for cobia collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 52 fish aged, 8 age classes were represented and there was one fish aged as 12 years old without total length (Table **1**). The average age of the sample was 5.6 years, and the standard deviation and standard error were 2.4 and 0.33, respectively.

Year-class data indicates that recruitment into the fishery begins at age 3, which corresponds to the 2006 year-class for cobia caught in 2008. The year-class 2004 dominated the sample (33%) (Figure 3).

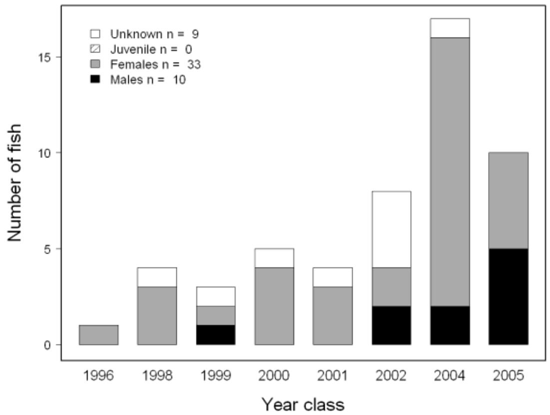


Figure 3. Year-class frequency distribution for cobia collected for ageing in 2008. Distribution is broken down by sex. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table **2**) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Franks, J.S., J.R. Warren, and M.V. Buchanan. 1999. Age and growth of cobia, Rachycentron canadum, from the northeastern Gulf of Mexico. Fish. Bull. 97:459-471.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

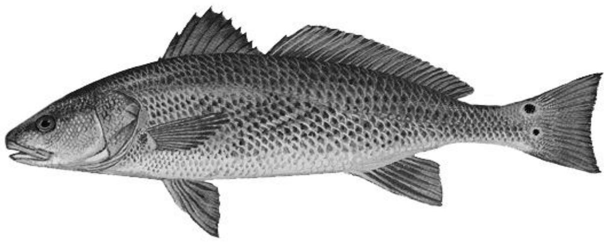
Table 1. The number of cobia assigned to each total length (inch)-at-age category for 51 fish sampled for otolith age determination in Virginia during 2008. There was one fish aged as 12 years old without total length.

	Age							
Interval	**3**	**4**	**6**	**7**	**8**	**9**	**10**	**Totals**
36 - 36.99	1	0	0	0	0	0	0	1
37 - 37.99	2	0	0	0	0	0	0	2
38 - 38.99	1	0	0	0	0	0	0	1
39 - 39.99	2	1	0	0	0	0	0	3
42 - 42.99	1	0	0	0	0	0	0	1
43 - 43.99	2	0	2	0	0	0	0	4
44 - 44.99	0	5	0	0	0	0	0	5
45 - 45.99	1	1	0	1	0	0	0	3
46 - 46.99	0	2	1	0	0	0	0	3
47 - 47.99	0	2	0	0	1	0	0	3
48 - 48.99	0	2	1	0	0	1	0	4
49 - 49.99	0	1	1	0	0	0	0	2
50 - 50.99	0	2	0	0	0	0	0	2
51 - 51.99	0	1	0	0	0	1	0	2
53 - 53.99	0	0	3	0	0	0	0	3
55 - 55.99	0	0	0	1	0	0	0	1
56 - 56.99	0	0	0	1	0	1	0	2
57 - 57.99	0	0	0	0	0	0	1	1
58 - 58.99	0	0	0	0	1	0	0	1
59 - 59.99	0	0	0	0	1	0	0	1
60 - 60.99	0	0	0	0	1	0	0	1
61 - 61.99	0	0	0	0	1	0	2	3
62 - 62.99	0	0	0	1	0	0	0	1
65 - 65.99	0	0	0	0	0	0	1	1
Totals	10	17	8	4	5	3	4	51

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for cobia sampled for age determination in Virginia during 2008.

	Age						
Interval	**3**	**4**	**6**	**7**	**8**	**9**	**10**
36 - 36.99	1	0	0	0	0	0	0
37 - 37.99	1	0	0	0	0	0	0
38 - 38.99	1	0	0	0	0	0	0
39 - 39.99	0.667	0.333	0	0	0	0	0
42 - 42.99	1	0	0	0	0	0	0
43 - 43.99	0.5	0	0.5	0	0	0	0
44 - 44.99	0	1	0	0	0	0	0
45 - 45.99	0.333	0.333	0	0.333	0	0	0
46 - 46.99	0	0.667	0.333	0	0	0	0
47 - 47.99	0	0.667	0	0	0.333	0	0
48 - 48.99	0	0.5	0.25	0	0	0.25	0
49 - 49.99	0	0.5	0.5	0	0	0	0
50 - 50.99	0	1	0	0	0	0	0
51 - 51.99	0	0.5	0	0	0	0.5	0
53 - 53.99	0	0	1	0	0	0	0
55 - 55.99	0	0	0	1	0	0	0
56 - 56.99	0	0	0	0.5	0	0.5	0
57 - 57.99	0	0	0	0	0	0	1
58 - 58.99	0	0	0	0	1	0	0
59 - 59.99	0	0	0	0	1	0	0
60 - 60.99	0	0	0	0	1	0	0
61 - 61.99	0	0	0	0	0.333	0	0.667
62 - 62.99	0	0	0	1	0	0	0
65 - 65.99	0	0	0	0	0	0	1

Chapter 5
Red Drum



Sciaenops ocellatus

INTRODUCTION

A total of 64 red drum, *Sciaenops ocellatus*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The average age of the sample was 2.4 years, with a standard deviation of 2.1 and a standard error of 0.26. Five age classes were represented with the youngest age of 1 and the oldest age of 16 years, comprising fish from the earliest year-class of 1992 to the most recent year-class of 2007.

METHODS

Handling of collection — Sagittal Otoliths (hereafter, refer to as "otoliths") were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory identification numbers. All otoliths were stored dry in their original labeled coin envelopes.

Preparation — Otoliths were processed for age determination following the methods described in Bobko (1991) and Jones and Wells (1998) for black drum. The left or right sagittal otolith was randomly selected and attached, distal side down, to a glass slide with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three-inch diameter, Norton® Diamond Grinding Wheels, separated by a stainless steel spacer of 0.4mm (diameter 2.5"). The position of the marked core fell within the 0.4mm space between the blades, such that the core was included in the thin-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx® mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the dark band deposition period, is interpreted as being toward the next age class.

For example, red drum otolith deposition occurs between March and May (Bobko 1991). A red drum captured between January 1 and May 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

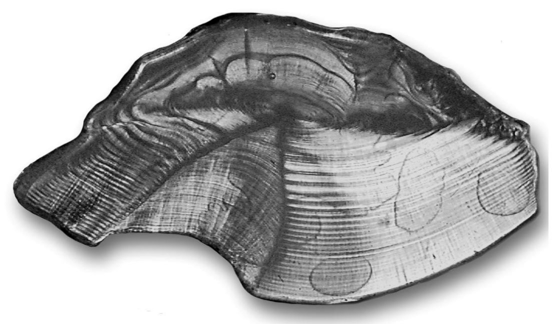


Figure 1. Otolith thin-section from 26 year old red drum.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis. Red drum year-class assignment was based on a January 1 annual birth date.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

The measurement of reader self-precision was very high for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV = 0.7% and an agreement of 96% (test of symmetry: $\chi^2 = 2$, df = 2, $P = 0.3679$). There is no significant difference between the first and second readings for Reader 2 with a CV = 0.1% and an agreement of 98% (test of symmetry: $\chi^2 = 1$, df = 1, $P = 0.3173$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 98.4% and a CV of 0.1% (test of symmetry: $\chi^2 = 1$, df = 1, $P = 0.3173$) (Figure 2).

Reader 1 had an agreement of 100% with ages of fish aged in 2000. Reader 2 had an agreement of 94% with ages of fish aged in 2000 with a CV of 1.5% (test of symmetry: $\chi^2 = 1$, df = 2, $P = 0.6065$).

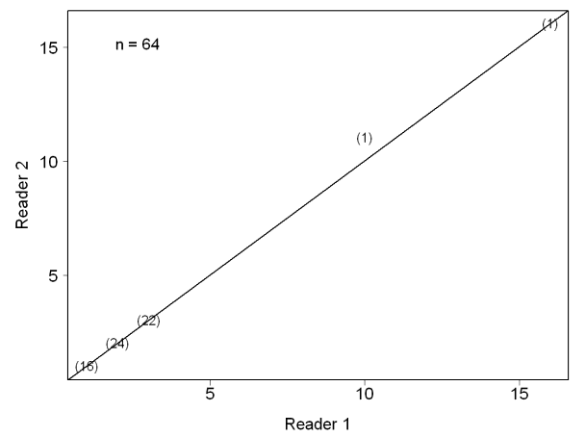


Figure 2. Between-reader comparison of otolith age estimates for red drum collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 64 fish aged with otoliths, 5 age classes were represented (Table 1). The average age of the sample was 2.4 years, and the standard deviation and standard error were 2.1 and 0.26, respectively. Year-class data indicate that the 2005, 2006, and 2007 year-classes dominated the sample. Indicative of the trend in the recreational fishing, very few older fish were collected in 2008 (Figure 3).

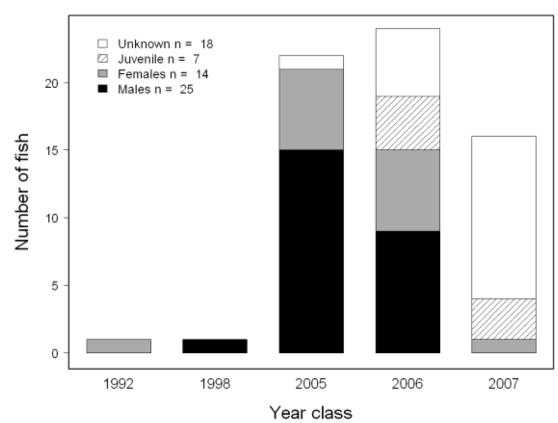


Figure 3. Year-class frequency distribution for red drum collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Bobko, S. J. 1991. Age, growth, and reproduction of black drum, *Pogonias cromis*, in Virginia. M.S. thesis. Old Dominion University, Norfolk, VA.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. The number of red drum assigned to each total length (inch)-at-age category for 64 fish sampled for otolith age determination in Virginia during 2008.

	Age					
Interval	**1**	**2**	**3**	**10**	**16**	**Totals**
13 - 13.99	3	0	0	0	0	3
14 - 14.99	4	0	0	0	0	4
15 - 15.99	3	0	0	0	0	3
17 - 17.99	0	1	0	0	0	1
18 - 18.99	5	4	0	0	0	9
19 - 19.99	1	2	0	0	0	3
20 - 20.99	0	1	1	0	0	2
21 - 21.99	0	1	0	0	0	1
22 - 22.99	0	3	1	0	0	4
23 - 23.99	0	2	1	0	0	3
24 - 24.99	0	7	2	0	0	9
25 - 25.99	0	2	6	0	0	8
26 - 26.99	0	0	5	0	0	5
27 - 27.99	0	0	5	0	0	5
28 - 28.99	0	1	1	0	0	2
44 - 44.99	0	0	0	1	0	1
46 - 46.99	0	0	0	0	1	1
Totals	16	24	22	1	1	64

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for red drum sampled for age determination in Virginia during 2008.

	Age				
Interval	**1**	**2**	**3**	**10**	**16**
13 - 13.99	1	0	0	0	0
14 - 14.99	1	0	0	0	0
15 - 15.99	1	0	0	0	0
17 - 17.99	0	1	0	0	0
18 - 18.99	0.556	0.444	0	0	0
19 - 19.99	0.333	0.667	0	0	0
20 - 20.99	0	0.5	0.5	0	0
21 - 21.99	0	1	0	0	0
22 - 22.99	0	0.75	0.25	0	0
23 - 23.99	0	0.667	0.333	0	0
24 - 24.99	0	0.778	0.222	0	0
25 - 25.99	0	0.25	0.75	0	0
26 - 26.99	0	0	1	0	0
27 - 27.99	0	0	1	0	0
28 - 28.99	0	0.5	0.5	0	0
44 - 44.99	0	0	0	1	0
46 - 46.99	0	0	0	0	1

Chapter 6
Atlantic Spadefish

Chaetodipterus faber

INTRODUCTION

We aged a total of 313 spadefish, *Chaetodipterus faber*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The spadefish ages ranged from 0 to 13 years old with an average age of 3, and standard deviation of 1.8, and a standard error of 0.1. Eleven age classes (0 to 7, 9 to 10, and 13) were represented, comprising fish from the 1995, 1998, 1999, and 2001 through 2008 year-classes. Fish from the 2005 year-class dominated the sample.

METHODS

Sample size for ageing — We estimated sample size for ageing spadefish in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spadefish in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spadefish collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spadefish used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory identification numbers. All otoliths were stored dry inside of protective Axygen 2.0ml labeled microtubes within their original labeled coin envelopes.

Preparation Due to their fragility, small spadefish sagittal otoliths (hereafter, referred to as "otoliths") (less than 14 mm x 5 mm x 3 mm in all dimensions) were processed for age determination using an embedding and thin-sectioning technique. In order to increase the contrast of opaque and translucent regions in the otolith matrices, both small and large spadefish otoliths were baked either before or after sectioning, respectively. The right or left otolith was selected randomly from every fish.

For small spadefish otoliths, a series of 14 mm x 5 mm x 3 mm wells (Ladd Industries silicon rubber mold) were pre-filled to half-volume with Loctite® 349 adhesive, and permitted to cure for 24 hours until solidified.

The small whole spadefish otoliths were placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400^{o}C. Baking time was otolith size dependent and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked otoliths could be individually placed into the pre-filled silicon rubber mold with Loctite® 349 adhesive.

The remaining volume of the wells were then filled with fresh, non-cured Loctite® 349 adhesive, at which point the small whole spadefish otoliths (baked) could be inserted into the wells on top of the solidified Loctite® 349 base, within a stable embedding atmosphere before sectioning. The otoliths were inserted into the fresh Loctite® 349 adhesive, proximal side up, with the long axis of the otolith exactly parallel with the long axis of the mold well. Once the otoliths were properly oriented within the Loctite® 349-filled wells, the mold was placed under UV light and left to solidify overnight. Once dry, each embedded otolith was removed from the mold and mounted with clear Crystalbond™ 509 onto a standard microscope slide. Once mounted, a small mark was made in permanent ink on the otolith-mold surface directly above the otolith focus, which was located using a stereo microscope under transmitted light. The embedded small spadefish otoliths could now be processed along with the larger spadefish otoliths.

Large spadefish otoliths were mounted directly with clear Crystalbond™ 509 adhesive onto a standard microscope slide with its distal surface orientated upwards. Once mounted, a small permanent-ink mark was placed on the otolith surface directly above the otolith focus, which was identified under a stereomicroscope in transmitted light. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). The otolith was positioned so that the blades straddled each side of the otolith focus marked by pencil. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the large otolith sections were placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400^{o}C until achieving the light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections. Small otolith sections of quality were mounted with Flo-texx directly.

Readings — The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period when it deposits an annulus. If the fish is captured after the end of the species- specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, spadefish otolith deposition occurs December through April (Hayse 1989). A spadefish captured between January 1 and April 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of April 30, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

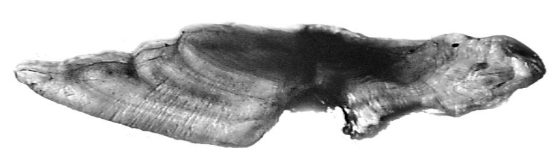


Figure 1. Sectioned otolith from a 3-year-old female spadefish.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 312 for ageing spadefish in 2008, ranging in length interval from 3 to 25 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 2 and the largest CV of 19% for age 5 fish. In 2008, we randomly selected and aged 313 fish from 383 spadefish collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 97 fish. Because those fish mainly fell within both modes of spadefish length distribution (Table 1), the precision for the estimates of both young and old age groups would be influenced significantly.

Measurements of reader self-precision were very good for both readers (Reader 1's CV = 1.3% and Reader 2's CV = 1.8%), higher than those in 2007 (Reader 1's CV = 5.2% and Reader 2's CV = 3.2%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: χ^2 = 16.27, df = 9, P = 0.0614) (Figure 2). The average coefficient of variation (CV) of 3.7% was good and lower than in 2007 (5.6%) with an higher agreement of 88.5 than in 2007 (80%) between two readers.

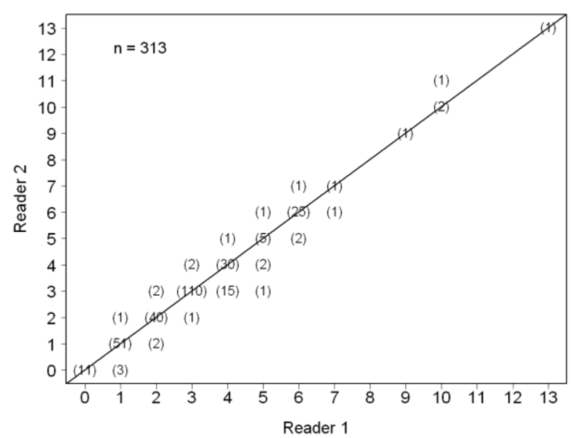


Figure 2. Between-reader comparison of otolith age estimates for spadefish collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

There is no time-series bias for both readers. Reader 1 had an agreement of 86% with ages of fish aged in 2003 with a

CV of 1.8% (test of symmetry: $\chi^2 = 5$, df = 4, P = 0.2873). Reader 2 had an agreement of 86% with ages of fish aged in 2003 with a CV of 1.8% (test of symmetry: $\chi^2 = 7$, df = 7, P = 0.4289).

Of the 313 fish aged, 11 age classes were represented (Table 2). The average age of the sample was 3 years, and the standard deviation and standard error were 1.8 and 0.1, respectively. Year-class data indicate that the 2005 year-class dominated the sample (38%) (Figure 3).

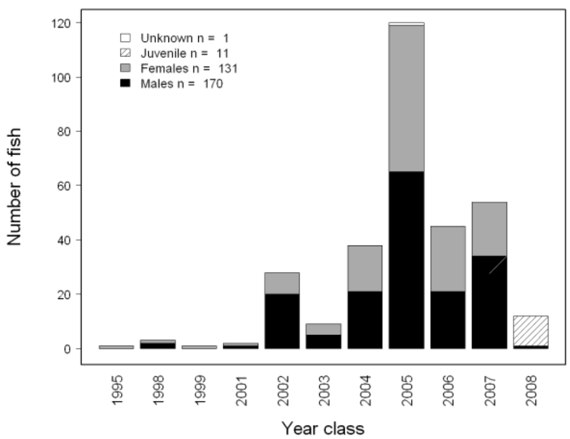


Figure 3. Year-class frequency distribution for spadefish collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hayse, J. W. 1989. Feeding habits, age, growth, and reproduction of Atlantic spadefish *Chaetodipterus faber (Piscies: Ephippidae)* in South Carolina. Fishery Bulletin 88: 67-83.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of spadefish collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged

Interval	Target	Collected	Aged	Need
3 - 3.99	5	8	8	0
4 - 4.99	5	8	7	0
5 - 5.99	11	31	22	0
6 - 6.99	34	25	24	10
7 - 7.99	44	29	28	16
8 - 8.99	37	26	26	11
9 - 9.99	23	18	18	5
10 - 10.99	13	39	28	0
11 - 11.99	9	27	18	0
12 - 12.99	7	47	32	0
13 - 13.99	9	39	28	0
14 - 14.99	7	22	13	0
15 - 15.99	10	15	13	0
16 - 16.99	8	6	5	3
17 - 17.99	9	13	13	0
18 - 18.99	10	10	11	0
19 - 19.99	14	8	8	6
20 - 20.99	19	5	5	14
21 - 21.99	14	4	4	10
22 - 22.99	9	1	1	8
23 - 23.99	5	1	1	4
24 - 24.99	5	0	0	5
25 - 25.99	5	0	0	5
Totals	312	382	313	97

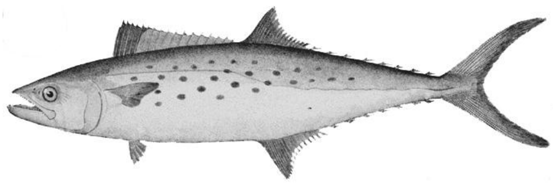
Table 2. The number of spadefish assigned to each total length-at-age category for 313 fish sampled for otolith age determination in Virginia during 2008.

	Age											
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**13**	**Totals**
3 - 3.99	8	0	0	0	0	0	0	0	0	0	0	8
4 - 4.99	3	4	0	0	0	0	0	0	0	0	0	7
5 - 5.99	1	17	3	0	1	0	0	0	0	0	0	22
6 - 6.99	0	21	2	1	0	0	0	0	0	0	0	24
7 - 7.99	0	8	15	5	0	0	0	0	0	0	0	28
8 - 8.99	0	4	10	12	0	0	0	0	0	0	0	26
9 - 9.99	0	0	8	10	0	0	0	0	0	0	0	18
10 - 10.99	0	0	4	17	7	0	0	0	0	0	0	28
11 - 11.99	0	0	1	16	1	0	0	0	0	0	0	18
12 - 12.99	0	0	1	24	3	1	3	0	0	0	0	32
13 - 13.99	0	0	0	19	8	1	0	0	0	0	0	28
14 - 14.99	0	0	1	8	3	1	0	0	0	0	0	13
15 - 15.99	0	0	0	3	6	1	2	1	0	0	0	13
16 - 16.99	0	0	0	0	4	1	0	0	0	0	0	5
17 - 17.99	0	0	0	2	3	1	6	0	1	0	0	13
18 - 18.99	0	0	0	2	1	1	6	0	0	1	0	11
19 - 19.99	0	0	0	0	0	1	6	0	0	1	0	8
20 - 20.99	0	0	0	1	1	0	3	0	0	0	0	5
21 - 21.99	0	0	0	0	0	1	2	1	0	0	0	4
22 - 22.99	0	0	0	0	0	0	0	0	0	0	1	1
23 - 23.99	0	0	0	0	0	0	0	0	0	1	0	1
Totals	12	54	45	120	38	9	28	2	1	3	1	313

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for spadefish sampled for age determination in Virginia during 2008.

	Age										
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**13**
3 - 3.99	1	0	0	0	0	0	0	0	0	0	0
4 - 4.99	0.429	0.571	0	0	0	0	0	0	0	0	0
5 - 5.99	0.045	0.773	0.136	0	0.045	0	0	0	0	0	0
6 - 6.99	0	0.875	0.083	0.042	0	0	0	0	0	0	0
7 - 7.99	0	0.286	0.536	0.179	0	0	0	0	0	0	0
8 - 8.99	0	0.154	0.385	0.462	0	0	0	0	0	0	0
9 - 9.99	0	0	0.444	0.556	0	0	0	0	0	0	0
10 - 10.99	0	0	0.143	0.607	0.25	0	0	0	0	0	0
11 - 11.99	0	0	0.056	0.889	0.056	0	0	0	0	0	0
12 - 12.99	0	0	0.031	0.75	0.094	0.031	0.094	0	0	0	0
13 - 13.99	0	0	0	0.679	0.286	0.036	0	0	0	0	0
14 - 14.99	0	0	0.077	0.615	0.231	0.077	0	0	0	0	0
15 - 15.99	0	0	0	0.231	0.462	0.077	0.154	0.077	0	0	0
16 - 16.99	0	0	0	0	0.8	0.2	0	0	0	0	0
17 - 17.99	0	0	0	0.154	0.231	0.077	0.462	0	0.077	0	0
18 - 18.99	0	0	0	0.182	0.091	0.091	0.545	0	0	0.091	0
19 - 19.99	0	0	0	0	0	0.125	0.75	0	0	0.125	0
20 - 20.99	0	0	0	0.2	0.2	0	0.6	0	0	0	0
21 - 21.99	0	0	0	0	0	0.25	0.5	0.25	0	0	0
22 - 22.99	0	0	0	0	0	0	0	0	0	0	1
23 - 23.99	0	0	0	0	0	0	0	0	0	1	0

Chapter 7
Spanish Mackerel



Scomberomorous maculatus

INTRODUCTION

We aged a total of 242 Spanish mackerel, *Scomberomorous maculatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The Spanish mackerel ages ranged from 0 to 9 years old with an average age of 1.4, and standard deviation of 1.3, and a standard error of 0.08. Eight age classes (0 to 6, and 9) were represented, comprising fish from the 1999, and 2002 through 2008 year-classes. Fish from the 2007 year-class dominated the sample (57%).

METHODS

Sample size for ageing — We estimated sample size for ageing Spanish mackerel in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing Spanish mackerel in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of Spanish mackerel collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of Spanish mackerel used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — All Sagittal otoliths (hereafter, referred to as "otoliths") and associated data were transferred to the Center for Quantitative Fisheries Ecology's Age and Growth Laboratory as they were collected. In the lab they were sorted by date of capture, their envelope labels verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry inside of protective Axygen 2.0 ml microtubes within their original labeled coin envelopes.

Preparation Due to their fragility, we used our embedding and thin-sectioning method to prepare Spanish mackerel otoliths for age determination. To start, a series of 14 mm x 5 mm x 3 mm wells (Ladd Industries silicon rubber mold) were pre-filled to half-volume with Loctite® 349 adhesive, and permitted to cure for 24 hours until solidified. The remaining volume in the wells was then filled with fresh, non-cured Loctite® 349 adhesive, at which point the whole Spanish mackerel otoliths could be inserted into the wells on top of the solidified Loctite® 349 base, suspended within a stable embedding atmosphere before sectioning. The otoliths were inserted into the fresh Loctite® 349 adhesive, distal side up, with the long axis of the otolith exactly parallel with the long axis of the mold well. Once the otoliths were properly oriented within the Loctite® 349 -filled wells, the mold was placed under UV light and left to solidify overnight. Once dry, each embedded otolith was removed from the mold and mounted with clear Crystalbond™ 509 onto a standard microscope slide. Once mounted, a small mark was made in permanent ink on the otolith-mold surface directly above the otolith focus, which was located using a stereo microscope under transmitted light. At least one transverse cross-section (hereafter, referred to as "thin-section) was then removed from marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). The otolith was positioned so that the wafering blades straddled each side of the focus ink mark. The glass slide was adjusted to ensure that the blades were exactly perpendicular to the long axis of the otolith. The otolith thin-section was viewed under a stereo microscope to determine which side (cut surface) of the otolith was closer to the focus. The otolith thin-section was mounted best-side up onto a glass slide with Flo-texx® mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Reading - The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x +

x", where "x" is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the end of annulus deposition period is interpreted as being toward the next age class.

For example, Spanish mackerel otolith deposition occurs between May and June (Fable et al. 1987). A Spanish mackerel captured between January 1 and June 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification. The first annulus on the thin-sections was often quite distant from the core, with subsequent annuli regularly spaced along the sulcal groove out towards the proximal (inner-face) edge of the otolith (Figure 1).

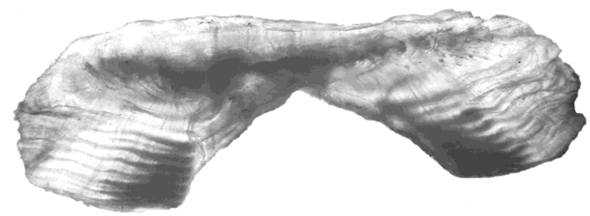


Figure 1. An eight year old Spanish mackerel otolith thin section from a 1 kg female.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 240 for ageing Spanish mackerel in 2007, ranging in length interval from 7 to 33 inches (Table 1). This sample size provided a range in CV for age composition approximately from the CV much smaller than 4% for age 1 and the largest CV of 24% for age 4 fish. In 2008, we randomly selected and aged 242 fish from 260 Spanish mackerel collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 57 fish. However, these were primarily from the very large length intervals (**Error! Reference source not found.**), therefore, the precision for the estimates of major age group (age 7) would not be influenced significantly.

The measurement of reader self-precision was good (Reader 1's CV = 2.2% and Reader 2's CV = 0), Reader 1's CV is similar to the one in 2007 (1.9%) and Reader 2's CV is significantly lower than the one in 2007 (2.7%). There was no evidence of systematic disagreement between reader 1 and reader 2 (test of symmetry: $\chi^2 = 4$, df = 3, $P = 0.2615$). The average between-reader coefficient of variation (CV) of 1.1 (3.4% in 2007) was good with an agreement of 96.7% (94% in 2007) between two readers (Figure 2).

There is no time-series bias for both readers. Reader 1 had an agreement of 94% with ages of fish aged in 2003 with a CV of 2.2% (test of symmetry: $\chi^2 = 1$, df = 2, $P = 0.6065$). Reader 2 had an agreement of 100% with ages of fish aged in 2003.

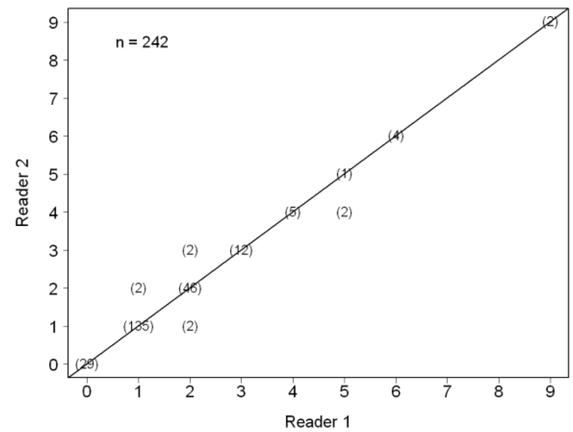


Figure 2. Between-reader comparison of otolith age estimates for Spanish mackerel collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 242 Spanish mackerel aged, 8 age classes were represented (Table 2). The average age was 1.4 year old, and the standard deviation and standard error were 1.3 and 0.08, respectively. Year-class data show that the fishery was comprised of 8 year-classes, comprising fish from the 1999, 2002 through 2008 year-classes, with 57% of fish from the 2007 year-classes (Figure 3).

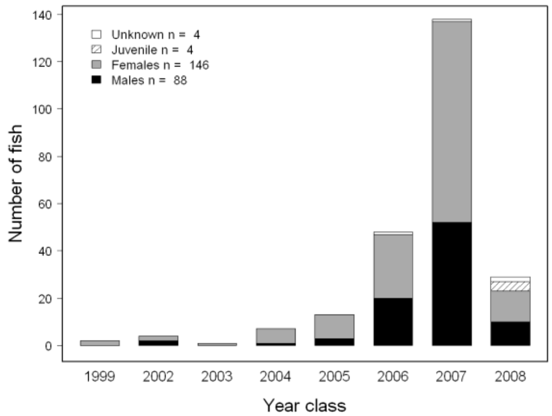


Figure 3. Year-class frequency distribution for Spanish mackerel collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for etermining the consistency of age terminations. Trans. Am. Fish. Soc. 124:131-138.

Fable, Jr., W. A., A. G. Johnson, and L. E. Barger. 1987. Age and growth of Spanish mackerel, Scomberomorus maculates, from Florida. Fishery Bulletin 85: 777-783.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Murphy E.O., R.S. Birdsong, J.A. Musick. 1997. Fishes of the Chesapeake Bay. Smithsonian Institute Press. Washington and London.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.or

Table 1. Number of Spanish mackerel collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7 - 7.99	5	0	0	5
8 - 8.99	5	1	1	4
9 - 9.99	5	2	2	3
10 - 10.99	5	0	0	5
11 - 11.99	5	2	2	3
12 - 12.99	5	8	8	0
13 - 13.99	5	8	7	0
14 - 14.99	10	20	20	0
15 - 15.99	30	36	35	0
16 - 16.99	35	41	36	0
17 - 17.99	23	41	35	0
18 - 18.99	15	21	18	0
19 - 19.99	12	21	19	0
20 - 20.99	10	12	12	0
21 - 21.99	9	13	13	0
22 - 22.99	6	15	15	0
23 - 23.99	5	4	4	1
24 - 24.99	5	6	6	0
25 - 25.99	5	2	2	3
26 - 26.99	5	2	2	3
27 - 27.99	5	2	2	3
28 - 28.99	5	1	1	4
29 - 29.99	5	0	0	5
30 - 30.99	5	1	1	4
31 - 31.99	5	1	1	4
32 - 32.99	5	0	0	5
33 - 33.99	5	0	0	5
Totals	240	260	242	57

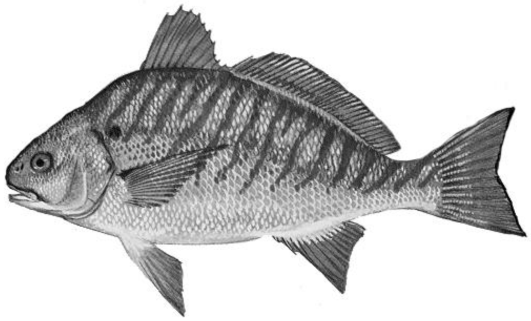
Table 2. The number of Spanish mackerel assigned to each total length-at-age category for 242 fish sampled for otolith age determination in Virginia during 2008.

	Age								
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**9**	**Totals**
8 - 8.99	1	0	0	0	0	0	0	0	1
9 - 9.99	2	0	0	0	0	0	0	0	2
11 - 11.99	1	1	0	0	0	0	0	0	2
12 - 12.99	4	4	0	0	0	0	0	0	8
13 - 13.99	2	4	1	0	0	0	0	0	7
14 - 14.99	1	19	0	0	0	0	0	0	20
15 - 15.99	18	16	0	0	1	0	0	0	35
16 - 16.99	0	36	0	0	0	0	0	0	36
17 - 17.99	0	29	6	0	0	0	0	0	35
18 - 18.99	0	12	6	0	0	0	0	0	18
19 - 19.99	0	9	9	0	1	0	0	0	19
20 - 20.99	0	6	5	1	0	0	0	0	12
21 - 21.99	0	1	7	4	0	0	1	0	13
22 - 22.99	0	0	12	3	0	0	0	0	15
23 - 23.99	0	1	2	0	1	0	0	0	4
24 - 24.99	0	0	0	3	2	0	1	0	6
25 - 25.99	0	0	0	2	0	0	0	0	2
26 - 26.99	0	0	0	0	0	0	1	1	2
27 - 27.99	0	0	0	0	1	1	0	0	2
28 - 28.99	0	0	0	0	1	0	0	0	1
30 - 30.99	0	0	0	0	0	0	0	1	1
31 - 31.99	0	0	0	0	0	0	1	0	1
Totals	29	138	48	13	7	1	4	2	242

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Spanish mackerel sampled for age determination in Virginia during 2008.

	Age							
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**9**
8 - 8.99	1	0	0	0	0	0	0	0
9 - 9.99	1	0	0	0	0	0	0	0
11 - 11.99	0.5	0.5	0	0	0	0	0	0
12 - 12.99	0.5	0.5	0	0	0	0	0	0
13 - 13.99	0.286	0.571	0.143	0	0	0	0	0
14 - 14.99	0.05	0.95	0	0	0	0	0	0
15 - 15.99	0.514	0.457	0	0	0.029	0	0	0
16 - 16.99	0	1	0	0	0	0	0	0
17 - 17.99	0	0.829	0.171	0	0	0	0	0
18 - 18.99	0	0.667	0.333	0	0	0	0	0
19 - 19.99	0	0.474	0.474	0	0.053	0	0	0
20 - 20.99	0	0.5	0.417	0.083	0	0	0	0
21 - 21.99	0	0.077	0.538	0.308	0	0	0.077	0
22 - 22.99	0	0	0.8	0.2	0	0	0	0
23 - 23.99	0	0.25	0.5	0	0.25	0	0	0
24 - 24.99	0	0	0	0.5	0.333	0	0.167	0
25 - 25.99	0	0	0	1	0	0	0	0
26 - 26.99	0	0	0	0	0	0	0.5	0.5
27 - 27.99	0	0	0	0	0.5	0.5	0	0
28 - 28.99	0	0	0	0	1	0	0	0
30 - 30.99	0	0	0	0	0	0	0	1
31 - 31.99	0	0	0	0	0	0	1	0

Chapter 8
Spot



Leiostomus xanthurus

INTRODUCTION

We aged a total of 205 spot, *Leiostomus xanthurus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The spot ages ranged from 0 to 4 years old with an average age of 1.5, and standard deviation of 0.6, and a standard error of 0.04. Five age classes (0 to 4) were represented, comprising fish from the 2004 to 2006 year-classes. Fish from the 2006 and 2007 year-classes dominated the sample with 36% and 57%, respectively.

METHODS

Sample size for ageing — We estimated sample size for ageing spot in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spot in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spot collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spot used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory identification numbers. All otoliths were stored dry inside of protective Axygen 2.0 ml microtubes within their original labeled coin envelopes.

Preparation — Sagittal otoliths (hereafter, referred to as "otoliths") were processed for age determination following our thin-sectioning method, as described in Chapters 1, 2 and 5 for other sciaenids. The left or right sagittal otolith was randomly selected and attached to a glass slide with clear Crystalbond™ 509 adhesive. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). The position of the marked core fell within the 0.3 mm space between the blades, such that the core was included in the transverse cross-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings - The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, spot otolith deposition occurs between May and July (Piner and Jones 2004). A spot captured between January 1 and July 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of July 31, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

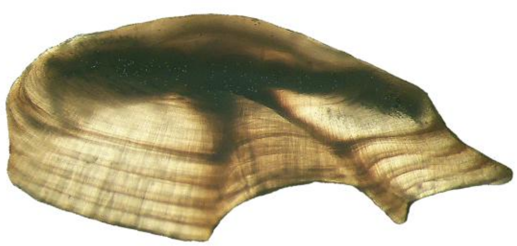


Figure 1. Sectioned otolith from a 5 year old spot.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 205 for ageing spot in 2008, ranging in length interval from 5 to 14 inches (Table 1). This sample size provided a range in CV for age composition approximately from the CV much smaller than 6% for age 1 and the largest CV of 19% for age 3 fish. In 2008, we randomly selected and aged 205 fish from 249 Spot collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 24 fish. However, these were primarily from the very large length intervals (Table 1), therefore, the precision for the estimates of major age groups (from age 4 to 8) would not be influenced significantly. However, the precision for older fish would be influenced significantly.

The measurement of reader self-precision was good for both readers. Reader 1 had 100% agreement and Reader 2 had 98% agreement with a CV of 2.8% (test of symmetry: $\chi^2 = 5.67$, df = 4, $P = 0.2255$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 8$, df = 4, $P = 0.0916$). The average between-reader coefficient of variation (CV) of 4.8% was good with an agreement of 95% between two readers (Figure 2). There is no time-series bias for both readers. Reader 1 had an agreement of 98% with ages of fish aged in 2000 with a CV of 2.8% (test of symmetry: $\chi^2 = 1$, df = 1, $P = 0.3173$). Reader 2 had an agreement of 100% with ages of fish aged in 2003.

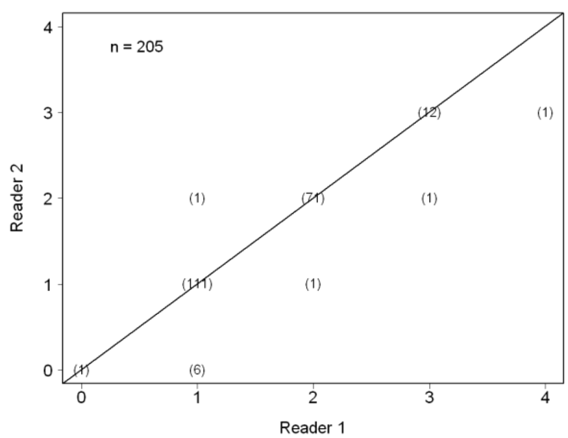


Figure 2. Between-reader comparison of otolith age estimates for spot collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 205 fish aged with otoliths, 5 age classes were represented (Table **2**). The average age for the sample was 1.5 years old, and the standard deviation and standard error were 0.6 and 0.04, respectively.

Year-class data show that the fishery was comprised of 5 year-classes, with fish spawned in both 2006 (36%) and 2007 (57%) dominating the catch (Figure 3).

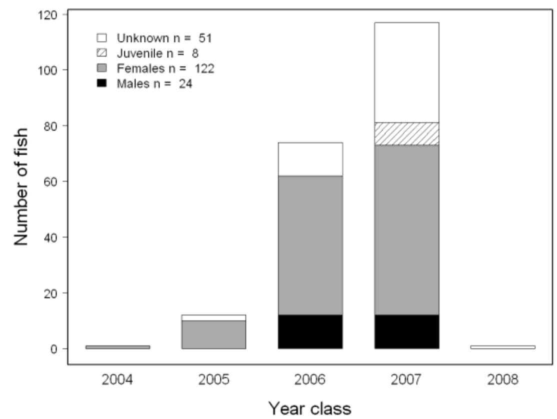


Figure 3. Year-class frequency distribution for spot collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table **3**) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Piner, K. R., and C. M. Jones. 2004. Age, growth and the potential for growth overfishing of spot (Leiostomus xanthurus) from the Chesapeake Bay, eastern USA. Marine and Freshwater Research 55: 553-560.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of spot collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
5 - 5.99	5	6	5	0
6 - 6.99	5	7	5	0
7 - 7.99	15	32	18	0
8 - 8.99	36	65	39	0
9 - 9.99	59	71	71	0
10 - 10.99	36	43	42	0
11 - 11.99	26	23	23	3
12 - 12.99	13	2	2	11
13 - 13.99	5	0	0	5
14 - 14.99	5	0	0	5
Totals	205	249	205	24

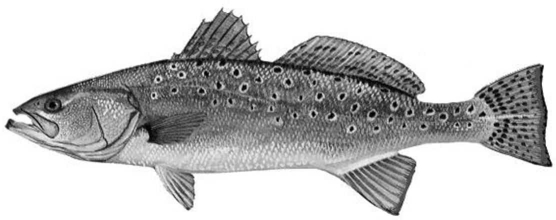
Table 2. The number of spot assigned to each total length-at-age category for 205 fish sampled for otolith age determination in Virginia during 2008.

	Age					
Interval	**0**	**1**	**2**	**3**	**4**	**Totals**
5 - 5.99	0	5	0	0	0	5
6 - 6.99	1	4	0	0	0	5
7 - 7.99	0	18	0	0	0	18
8 - 8.99	0	30	7	2	0	39
9 - 9.99	0	37	30	4	0	71
10 - 10.99	0	12	26	3	1	42
11 - 11.99	0	11	10	2	0	23
12 - 12.99	0	0	1	1	0	2
Totals	1	117	74	12	1	205

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for spot sampled for age determination in Virginia during 2008.

	Age				
Interval	**0**	**1**	**2**	**3**	**4**
5 - 5.99	0	1	0	0	0
6 - 6.99	0.2	0.8	0	0	0
7 - 7.99	0	1	0	0	0
8 - 8.99	0	0.769	0.179	0.051	0
9 - 9.99	0	0.521	0.423	0.056	0
10 - 10.99	0	0.286	0.619	0.071	0.024
11 - 11.99	0	0.478	0.435	0.087	0
12 - 12.99	0	0	0.5	0.5	0

Chapter 9
Spotted Seatrout



Cynoscion nebulosus

INTRODUCTION

We aged a total of 231 spotted seatrout, *Cynoscion nebulosus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The spotted seatrout ages ranged from 0 to 8 years old with an average age of 1.4, and standard deviation of 1.1, and a standard error of 0.07. Seven age classes (0 to 5, and 8) were represented, comprising fish from the 2000, 2003 through 2008 year-classes. Fish from the 2007 year-class dominated the sample with 51%, followed by 2006 (21%).

METHODS

Sample size for ageing — We estimated sample size for ageing spotted seatrout in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spotted seatrout in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spotted seatrout collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spotted seatrout used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Sagittal otoliths (hereafter, referred to as "otoliths") were received by the Age & Growth Laboratory in labeled coin envelopes. They were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry inside of protective Axygen 2.0 ml microtubes inside of their original labeled coin envelopes.

Preparation — Because spotted seatrout otolith material is used for additional projects at the CQFE, preparation of these otoliths for age determination required modeification of our thin-sectioning method, as introduced in Chapters 1, 2, 5, and 8 for other sciaenids. The left or right sagittal otolith was randomly selected and attached to a glass slide with clear silicone verus clear Crystalbond™ 509 adhesive. This prevented contamination of the otolith by the Crystalbond™ 509 and easy removal of the remaining otolith halves from the mounting slide after sectioning. Once mounted, the otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). The position of the marked core fell within the 0.3 mm space between the blades, such that the core was included in the transverse cross-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings – The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, spotted seatrout otolith deposition occurs between April and May (Murphy and Taylor 1994). A spotted seatrout captured between January 1 and

May 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

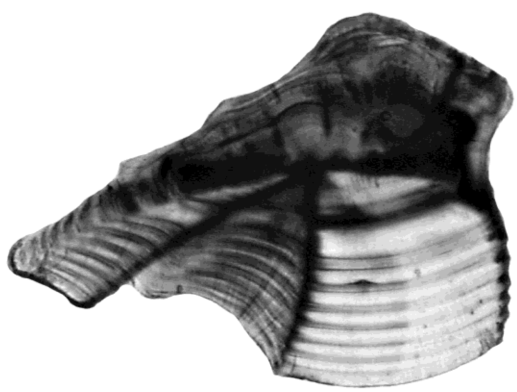


Figure 1. Sectioned otolith from an 8 year old, male spotted seatrout.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 285 for ageing spotted seatrout in 2008, ranging in length interval from 4 to 33 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 4% for age 1 and the largest CV of 24% for age 4 fish. In 2007, we randomly selected and aged 231 fish from 233 spotted seatrout collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 80 fish. However, these were primarily from the large length intervals (Table 1), therefore, the precision for older fish would be influenced significantly.

The measurement of reader self-precision was very high with the CV of 0 for both readers. There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 7$, df = 3, P = 0.0719). The average between-reader coefficient of variation (CV) of 1.1% was very good with an agreement of 97% between two readers (Figure 2).

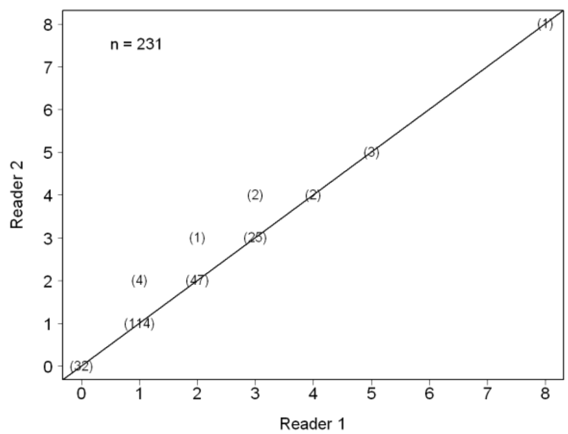


Figure 2. Between-reader comparison of otolith age estimates for speckled trout collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

There is no time-series bias for both readers. Both Reader 1 and Reader 2 had a 100% with ages of fish aged in 2000.

Of the 231 fish aged with otoliths, 7 age classes were represented (Table 2). The average age for the sample was 1.4 years old, and the standard deviation and standard error were 1.1 and 0.07, respectively. Year-class data show that the fishery was comprised of 7 year-classes, comprising fish from the 2000, 2003 through 2008 year-classes, with fish primarily from the 2007 (51%) year-classes (Figure 3).

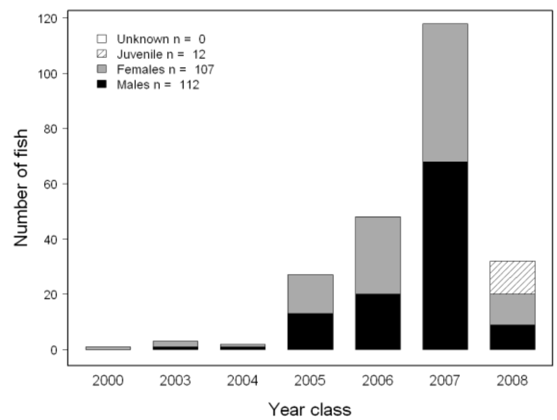


Figure 3. Year-class frequency distribution for speckled trout collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Murphy, M. D., and R. G. Taylor. 1994. Age, growth and mortality of spotted seatrout in Florida waters.

Transactions of American Fisheries Society 123: 482-497.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of speckled trout collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
4 - 4.99	5	0	0	5
5 - 5.99	5	0	0	5
6 - 6.99	5	2	2	3
7 - 7.99	5	1	1	4
8 - 8.99	5	1	1	4
9 - 9.99	5	5	5	0
10 - 10.99	5	14	14	0
11 - 11.99	13	13	13	0
12 - 12.99	14	11	11	3
13 - 13.99	10	6	6	4
14 - 14.99	12	13	13	0
15 - 15.99	16	14	14	2
16 - 16.99	21	35	35	0
17 - 17.99	27	24	24	3
18 - 18.99	20	15	15	5
19 - 19.99	20	22	22	0
20 - 20.99	18	18	17	1
21 - 21.99	9	6	6	3
22 - 22.99	11	9	9	2
23 - 23.99	8	6	6	2
24 - 24.99	6	7	6	0
25 - 25.99	5	5	5	0
26 - 26.99	5	3	3	2
27 - 27.99	5	0	0	5
28 - 28.99	5	1	1	4
29 - 29.99	5	1	1	4
30 - 30.99	5	1	1	4
31 - 31.99	5	0	0	5
32 - 32.99	5	0	0	5
33 - 33.99	5	0	0	5
Totals	285	233	231	80

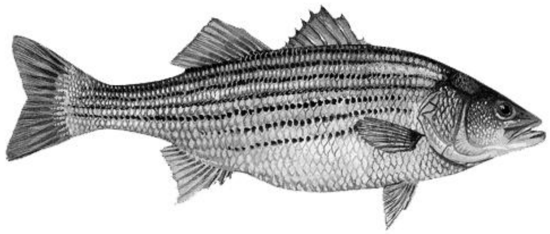
Table 2. The number of speckled trout assigned to each total length-at-age category for 231 fish sampled for otolith age determination in Virginia during 2008.

	Age							
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**8**	**Totals**
6 - 6.99	2	0	0	0	0	0	0	2
7 - 7.99	1	0	0	0	0	0	0	1
8 - 8.99	1	0	0	0	0	0	0	1
9 - 9.99	5	0	0	0	0	0	0	5
10 - 10.99	13	1	0	0	0	0	0	14
11 - 11.99	8	5	0	0	0	0	0	13
12 - 12.99	0	10	1	0	0	0	0	11
13 - 13.99	2	3	1	0	0	0	0	6
14 - 14.99	0	13	0	0	0	0	0	13
15 - 15.99	0	13	1	0	0	0	0	14
16 - 16.99	0	29	5	1	0	0	0	35
17 - 17.99	0	20	4	0	0	0	0	24
18 - 18.99	0	9	6	0	0	0	0	15
19 - 19.99	0	10	10	2	0	0	0	22
20 - 20.99	0	5	7	5	0	0	0	17
21 - 21.99	0	0	5	1	0	0	0	6
22 - 22.99	0	0	7	2	0	0	0	9
23 - 23.99	0	0	1	3	2	0	0	6
24 - 24.99	0	0	0	5	0	1	0	6
25 - 25.99	0	0	0	5	0	0	0	5
26 - 26.99	0	0	0	3	0	0	0	3
28 - 28.99	0	0	0	0	0	1	0	1
29 - 29.99	0	0	0	0	0	1	0	1
30 - 30.99	0	0	0	0	0	0	1	1
Totals	32	118	48	27	2	3	1	231

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for speckled trout sampled for age determination in Virginia during 2008.

	Age						
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**8**
6 - 6.99	1	0	0	0	0	0	0
7 - 7.99	1	0	0	0	0	0	0
8 - 8.99	1	0	0	0	0	0	0
9 - 9.99	1	0	0	0	0	0	0
10 - 10.99	0.929	0.071	0	0	0	0	0
11 - 11.99	0.615	0.385	0	0	0	0	0
12 - 12.99	0	0.909	0.091	0	0	0	0
13 - 13.99	0.333	0.5	0.167	0	0	0	0
14 - 14.99	0	1	0	0	0	0	0
15 - 15.99	0	0.929	0.071	0	0	0	0
16 - 16.99	0	0.829	0.143	0.029	0	0	0
17 - 17.99	0	0.833	0.167	0	0	0	0
18 - 18.99	0	0.6	0.4	0	0	0	0
19 - 19.99	0	0.455	0.455	0.091	0	0	0
20 - 20.99	0	0.294	0.412	0.294	0	0	0
21 - 21.99	0	0	0.833	0.167	0	0	0
22 - 22.99	0	0	0.778	0.222	0	0	0
23 - 23.99	0	0	0.167	0.5	0.333	0	0
24 - 24.99	0	0	0	0.833	0	0.167	0
25 - 25.99	0	0	0	1	0	0	0
26 - 26.99	0	0	0	1	0	0	0
28 - 28.99	0	0	0	0	0	1	0
29 - 29.99	0	0	0	0	0	1	0
30 - 30.99	0	0	0	0	0	0	1

Chapter 10
Striped Bass



Morone saxatilis

INTRODUCTION

We aged a total of 1132 striped bass, *Morone saxatilis*, using their scales collected by the VMRC's Biological Sampling Program in 2008. Of 1132 aged fish, 645 and 487 fish were collected in Chesapeake Bay (bay fish) and Atlantic waters (ocean fish) of Virginia, respectively. The average age for the bay fish was 8.8 years with a standard deviation of 3.3 and a standard error of 0.13. Seventeen age classes (3 to 18 and 22) were represented in the bay fish, comprising fish from the 1986, 1990 through 2005 year classes. The year class of 1993 was dominant in the bay fish sample in 2008 followed by the year classes of 1995 through 2002. The average age for the ocean fish was 9.9 years with a standard deviation of 2.6 and a standard error of 0.12. Fourteen age classes (5 to 17 and 20) were represented in the ocean fish, comprising fish from the 1988, 1991 to 2003 year classes. The year class of 1991 was dominant in the ocean fish sample in 2008, followed by the year classes of 1995 through 2000. We also aged a total of 258 fish using their otoliths in addition to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were to one another (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing striped bass collected in both Chesapeake Bay and Atlantic waters of Virginia in 2008, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing striped bass in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of striped bass collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of striped bass used by VMRC to estimate length distribution of the caches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to decide A (number of fish) is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Sagittal otoliths (hereafter, referred to as "otoliths") and scales were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and scales were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

Preparation —

Scales – Striped bass scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and which were of uniform size. We selected a range of four to six preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure:	15000 psi
Temperature:	77°C (170°F)
Time:	5 to 10 min

Striped bass scales that were the size of a quarter (coin) or larger, were pressed individually for up to twenty minutes. After pressing, the impressions were viewed with a Bell and Howell microfiche reader and checked again for regeneration and incomplete margins. Impressions that were too light, or when all scales were regenerated a new impression was made using different scales from the same fish.

Otoliths — We used a thin-section and bake technique to process striped bass otoliths for age determination. Otolith preparation began by randomly selecting either the right or left otolith. The otolith was mounted with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three inch diameter, Norton® Diamond Grinding Wheels(hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.4mm (diameter 2.5"). The otolith was positioned so that the blades straddled each side of the otolith focus pencil mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the otolith thin-section was placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was dependent on otolith size and gauged by color, with a light, caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx® mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, striped bass otolith deposition occurs between April and June (Secor et al. 1995). A striped bass captured between January 1 and June 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4 + 4.

Striped bass scales are also considered to have a deposition period of April through June (Secor et al. 1995), and age class assignment using these hard-parts is conducted in the same way as otoliths.

All striped bass samples (scale pressings and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish again without any knowledge of previously estimated ages or lengths, then assigned a final age to the fish. When the age readers were unable to agree on a final age, the fish was excluded from further analysis.

Scales - We determined fish age by viewing acetate impressions of scales (Figure 1) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses. Annuli on striped bass scales are identified based on two scale microstructure features, "crossing over" and circuli disruption. Primarily, "crossing over" in the lateral margins near the posterior\anterior interface of the scale is used to determine the origin of the annulus. Here compressed circuli (annulus) "cross over" the previously deposited circuli of the previous year's growth. Typically annuli of the first three years can be observed transversing this interface as dark bands. These bands remain consistent throughout the posterior field and rejoin the posterior\anterior interface on the opposite side of the focus. Annuli can also be observed in the anterior lateral field of the scale. Here the annuli typically reveal a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are typically associated with the disruption of circuli.

Figure 1. Scale impression of a 5-year-old male striped bass.

Annuli can also be observed bisecting the perpendicular plain of the radial striations in the anterior field of the scale. Radii emanate out from the focus of the scale towards the outer corner margins of the anterior field. These radial striations consist mainly of segmented concave circuli. The point of intersection between radii and annuli results in a "straightening out" of the concave circuli. This straightening of the circuli should be consistent throughout the entire anterior field of the scale. This event is further amplified by the presence of concave circuli neighboring both directly above and below the annulus. The first year's annulus can be difficult to locate on some scales. It is typically best identified in the lateral field of the anterior portion of the scale. The distance from the focus to the first year's annulus is typically larger with respect to the following annuli. For the annuli two through six, summer growth generally decreases proportionally. For ages greater than six, a crowding effect of the annuli near the outer margins of the scale is observed. This crowding effect creates difficulties in edge interpretation. At this point it is best to focus on the straightening of the circuli at the anterior margins of the scale.

When ageing young striped bass, zero through age two, extreme caution must be taken as not to over age the structure. In young fish there is no point of reference to aid in the determination of the first year; this invariably results in over examination of the scale and such events as hatching or saltwater incursion marks (checks) may be interpreted as the first year.

<u>Otoliths</u> – All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 2).

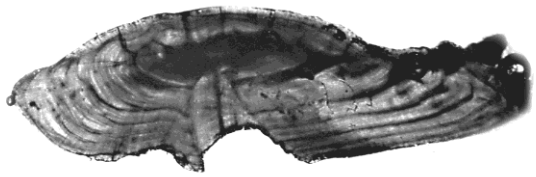


Figure 2. Otolith thin-section of a 5-year-old male striped bass.

By convention an annulus is identified as the narrow opaque zone, or winter growth. Typically the first year's annulus can be determined by first locating the focus of the otolith. The focus is generally located, depending on preparation, in the center of the otolith, and is visually well defined as a dark oblong region. The first year's annulus can be located directly below the focus, along the outer ridge of the sulcal groove on the ventral and dorsal sides of the otolith. This insertion point along the sulcal ridge resembles a check mark (not to be confused with a false annulus). Here the annulus can be followed outwards along the ventral and dorsal surfaces where it encircles the focus. Subsequent annuli also emanate from the sulcal ridge; however, they do not encircle the focus, but rather travel outwards to the distal surface of the otolith. To be considered a true annulus, each annulus must be rooted in the sulcus and travel without interruption to the distal surface of the otolith. The annuli in striped bass have a tendency to split as they advance towards the distal surface. As a result, it is critical that reading path proceed in a direction down the sulcal ridge and outwards to the distal surface.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between scale and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 628 for ageing the bay striped bass in 2008, ranging in length interval from 7 to 53 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 10% for age 9 and 10 to the largest CV of 23% for age 3 and 13 of the bay fish. We randomly selected and aged 645 fish from 905 striped bass collected by VMRC in Chesapeake Bay in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 101 fish, mainly in the very small and large length intervals (Table 1), as a result, the precision for the estimates of the majority of age categories would not be influenced significantly.

We estimated a sample size of 501 for ageing the ocean striped bass in 2008, ranging in length interval from 14 to 53 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 8% for age 9 and 10 to the largest CV of 25% for age 6 of the ocean fish. We aged all 487 striped bass collected by VMRC in Atlantic waters of Virginia in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 175 fish, from among the small, medium, and large length intervals (Table 2), as a result, the precision for the estimates of all age groups would be influenced significantly.

Scales — The measurement of reader self-precision was good for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV = 4.9% (test of symmetry: $\chi^2 = 14$, df = 12, $P = 0.3007$). There is no significant difference between the first and second readings for Reader 2 with a CV = 2.2% (test of symmetry: $\chi^2 = 8$, df = 9, $P = 0.5341$). There was an evidence of systematic disagreement between Reader 1 and Reader 2 with a CV of 4.1% (test of symmetry: $\chi^2 = 129.37$, df = 45, $P < 0.0001$) (Figure 3). The CV of 4.1% was fair. The between-reader agreement for scale for one year or less was 89% of all aged fish very similar to 90% in 2006.

There is no time-series bias for both readers. 88% of the age readings by Reader 1 in 2008 had either an agreement with or one-year difference from those fish aged in 2000 with a CV of 8.3% (test of symmetry: $\chi^2 = 12.3$, df = 14, $P = 0.5822$). The age readings of 97% fish by Reader 2 in 2008 had either an agreement with or one-year different from those fish aged in 2000 with a CV of 5.7% (test of symmetry: $\chi^2 = 15$, df = 12, $P = 0.2414$).

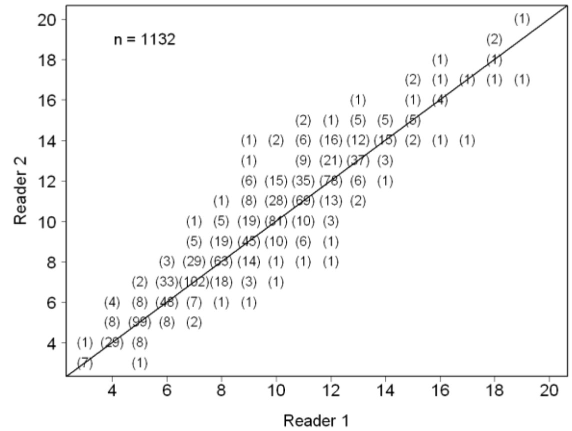


Figure 3. Between-reader comparison of scale age estimates for striped bass collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

Of the 645 bay striped bass aged with scales, 17 age classes (3 to 18 and 22) were represented (Table 3). The average age for the sample was 8.8 years. The standard deviation and standard error were 3.3 and 0.13, respectively. Year-class data (Figure 4) indicates that recruitment into the fishery in Chesapeake Bay begins at age 3, which corresponds to the 2005 year-class for striped bass caught in 2008. The year class of 2003 (age 5) striped bass was dominated in the sample in 2008. The sex ratio of male to female was 1:1.21 for the bay fish.

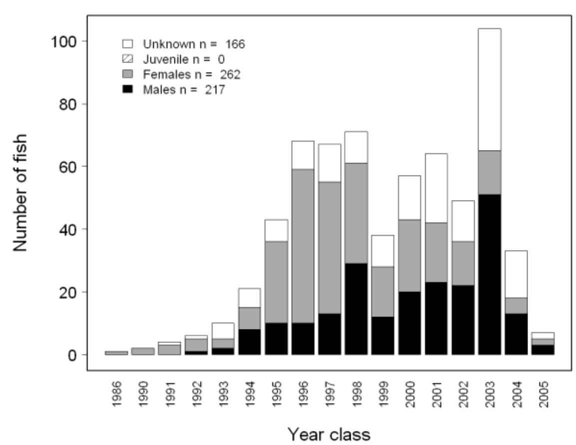


Figure 4. Year-class frequency distribution for

striped bass collected in Chesapeake Bay of Virginia for ageing in 2008. Distribution is broken down by sex and estimated using scale ages. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Of the 487 ocean striped bass aged with scales, 14 age classes (5 to 17 and 20) were represented (Table 4). The average age for the sample was 9.9 years. The standard deviation and standard error were 2.6 and 0.12, respectively. Year-class data (Figure 5) indicates that recruitment into the fishery in Atlantic waters of Virginia begins at age 5, which corresponds to the 2003 year-class for striped bass caught in 2005. The year class of 2001 (age 7) striped bass was dominated in the sample in 2008. The sex ratio of male to female was 1:2.64 for the ocean fish.

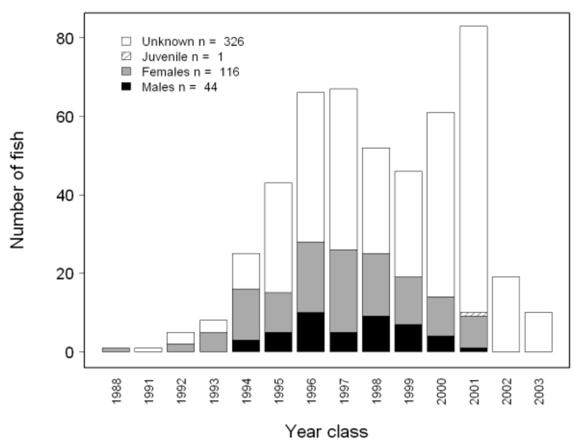


Figure 5. Year-class frequency distribution for striped bass collected in Virginia waters of Atlantic for ageing in 2008. Distribution is broken down by sex and estimated using scale ages. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Otoliths — The measurement of reader self-precision was very good for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV of 0.5% and an agreement of 92% (test of symmetry: $\chi^2 = 4$, df = 4, $P = 0.4060$). There is no significant difference between the first and second readings for Reader 2 with a CV of 0.9% and an agreement of 90% (test of symmetry: $\chi^2 = 5$, df = 5, $P = 0.4159$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 84% and a CV of 1.1% (test of symmetry: $\chi^2 = 17.94$, df = 17, $P = 0.3927$) (Figure 6).

There is no time-series bias for both readers. Reader 1 had an agreement of 85% with the fish aged in 2003 with a CV of 1.5% (test of symmetry: $\chi^2 = 9$, df = 8, $P = 0.3423$). Reader 2 had an agreement of 88% with the fish aged in 2003 with a CV of 1.5% (test of symmetry: $\chi^2 = 7$, df = 4, $P = 0.1359$).

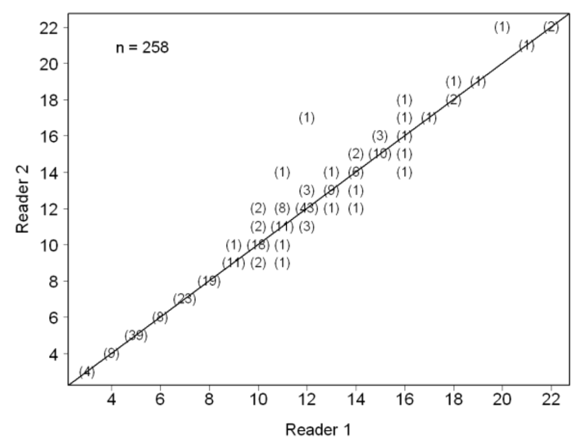


Figure 6. Between-reader comparison of otolith age estimates for striped bass collected in Chesapeake Bay and Virginia waters of theAtlantic in 2008.

Of 258 fish aged with otoliths, 21 age classes (3 to 23) were represented for striped bass aged with otoliths. The average age for the sample was 9.9 years. The standard deviation and standard error were 3.9 and 0.24, respectively.

Comparison of Scale and Otolith Ages — We aged 258 striped bass using both their scales and otoliths. There was evidence of systematic disagreement between otolith and scale ages (test of symmetry: $\chi^2 = 91.3$, df $= 44$, $P < 0.0001$) with an average CV of 7.4%. There was an agreement of 42% between scale and otoliths ages whereas scales were assigned a lower and higher age than otoliths for 35% and 23% of the fish, respectively (Figure 7). There was also evidence of bias between otolith and scale ages using an age bias plot (Figure 8), with scale generally assigned higher ages for younger fish and lower ages for older fish than otoliths age estimates.

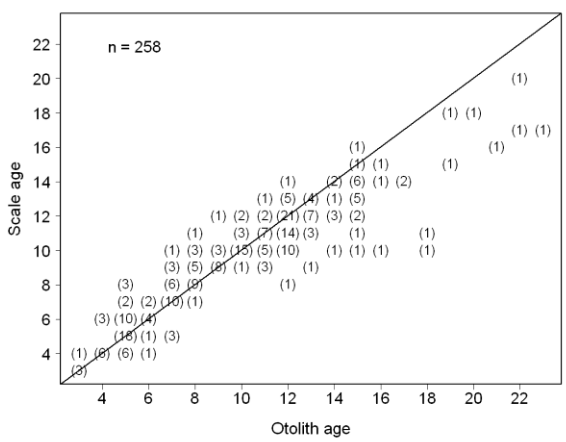


Figure 7. Comparison of scale and otolith age estimates for striped bass collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

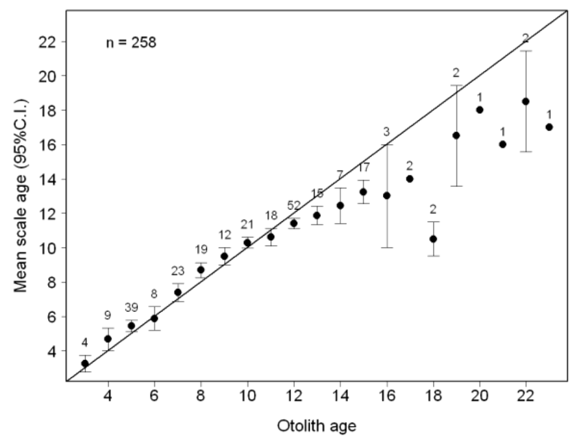


Figure 8. Age-bias plot for striped bass scale and otolith age estimates in 2008.

Age-Length-Key (ALK) — We developed an age-length-key for both bay (Table 5) and ocean fish (Table 6) using scale ages, separately. The ALK can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

RECOMMENDATIONS

We recommend that VMRC and ASMFC use otoliths for ageing striped bass. Although preparation time is greater for otoliths compared to scales, nonetheless as the mean age of striped bass increases in the recovering fishery, otoliths should provide more reliable estimates of age. We will continue to compare the age estimates between otoliths and scales.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Secor, D. H., T. M. Trice, and H. T. Hornick. 1995. Validation of otolith-based ageing and a comparison of otolith and scale-based ageing in mark-recaptured Chesapeake Bay striped bass, *Morone saxatilis*. Fishery Bulletin 93: 186-190.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of striped bass collected in the Chesapeake Bay of Virginia in 2008 and scale-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7 - 7.99	5	1	0	5
8 - 8.99	5	0	0	5
9 - 9.99	5	0	0	5
10 - 10.99	5	0	0	5
11 - 11.99	5	0	0	5
12 - 12.99	5	0	0	5
13 - 13.99	5	0	0	5
14 - 14.99	5	0	0	5
15 - 15.99	5	0	0	5
16 - 16.99	5	0	0	5
17 - 17.99	5	1	1	4
18 - 18.99	9	18	14	0
19 - 19.99	18	46	36	0
20 - 20.99	20	27	24	0
21 - 21.99	24	33	33	0
22 - 22.99	29	25	24	5
23 - 23.99	33	29	29	4
24 - 24.99	31	41	34	0
25 - 25.99	30	29	29	1
26 - 26.99	24	28	28	0
27 - 27.99	23	22	22	1
28 - 28.99	19	42	31	0
29 - 29.99	15	24	16	0
30 - 30.99	15	26	18	0
31 - 31.99	16	33	19	0
32 - 32.99	21	26	21	0
33 - 33.99	22	39	23	0
34 - 34.99	28	48	32	0
35 - 35.99	28	60	34	0
36 - 36.99	38	88	46	0
37 - 37.99	31	97	40	0
38 - 38.99	15	36	20	0
39 - 39.99	10	31	17	0
40 - 40.99	9	20	19	0
41 - 41.99	5	8	8	0
42 - 42.99	5	7	7	0
43 - 43.99	5	6	6	0
44 - 44.99	5	4	4	1
45 - 45.99	5	5	5	0
46 - 46.99	5	2	2	3
47 - 47.99	5	2	2	3
48 - 48.99	5	0	0	5
49 - 49.99	5	0	0	5
50 - 50.99	5	0	0	5
51 - 51.99	5	0	0	5
52 - 52.99	5	1	1	4
53 - 53.99	5	0	0	5
Totals	628	905	645	101

Table 2. Number of striped bass collected in Virginia waters of Atlantic in 2008 and scale-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
14 - 14.99	5	0	0	5
21 - 21.99	5	0	0	5
26 - 26.99	5	0	0	5
27 - 27.99	5	5	5	0
28 - 28.99	10	33	33	0
29 - 29.99	10	51	51	0
30 - 30.99	17	51	51	0
31 - 31.99	21	32	32	0
32 - 32.99	32	24	24	8
33 - 33.99	51	22	22	29
34 - 34.99	59	23	23	36
35 - 35.99	62	34	34	28
36 - 36.99	57	46	46	11
37 - 37.99	56	53	53	3
38 - 38.99	21	37	37	0
39 - 39.99	11	33	33	0
40 - 40.99	9	22	22	0
41 - 41.99	5	6	6	0
42 - 42.99	5	5	5	0
43 - 43.99	5	4	4	1
44 - 44.99	5	3	3	2
45 - 45.99	5	1	1	4
46 - 46.99	5	0	0	5
47 - 47.99	5	0	0	5
48 - 48.99	5	0	0	5
49 - 49.99	5	0	0	5
50 - 50.99	5	0	0	5
51 - 51.99	5	0	0	5
52 - 52.99	5	2	2	3
53 - 53.99	5	0	0	5
Totals	1002	487	487	676

Table 3. The number of striped bass assigned to each total length-at-age category for 645 fish sampled for scale age determination in Chesapeake Bay of Virginia during 2008.

	Age																	
Interval	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**22**	**Totals**
17 - 17.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18 - 18.99	0	3	6	5	0	0	0	0	0	0	0	0	0	0	0	0	0	14
19 - 19.99	2	12	17	2	3	0	0	0	0	0	0	0	0	0	0	0	0	36
20 - 20.99	0	3	15	4	2	0	0	0	0	0	0	0	0	0	0	0	0	24
21 - 21.99	1	5	18	6	3	0	0	0	0	0	0	0	0	0	0	0	0	33
22 - 22.99	0	3	14	5	1	0	1	0	0	0	0	0	0	0	0	0	0	24
23 - 23.99	2	3	15	4	1	4	0	0	0	0	0	0	0	0	0	0	0	29
24 - 24.99	0	2	10	6	10	2	3	1	0	0	0	0	0	0	0	0	0	34
25 - 25.99	0	1	7	7	5	6	0	1	2	0	0	0	0	0	0	0	0	29
26 - 26.99	1	1	2	5	8	6	0	3	1	1	0	0	0	0	0	0	0	28
27 - 27.99	0	0	0	1	12	4	3	0	2	0	0	0	0	0	0	0	0	22
28 - 28.99	0	0	0	3	5	9	0	8	4	0	1	0	0	0	1	0	0	31
29 - 29.99	0	0	0	1	3	3	4	1	2	1	1	0	0	0	0	0	0	16
30 - 30.99	0	0	0	0	3	4	3	2	2	2	1	1	0	0	0	0	0	18
31 - 31.99	0	0	0	0	4	5	2	3	0	2	0	2	0	1	0	0	0	19
32 - 32.99	0	0	0	0	2	5	1	8	1	2	2	0	0	0	0	0	0	21
33 - 33.99	0	0	0	0	1	3	6	6	2	1	1	2	0	1	0	0	0	23
34 - 34.99	0	0	0	0	1	6	4	8	8	1	1	1	2	0	0	0	0	32
35 - 35.99	0	0	0	0	0	0	9	10	7	3	3	2	0	0	0	0	0	34
36 - 36.99	0	0	0	0	0	0	2	9	12	17	6	0	0	0	0	0	0	46
37 - 37.99	0	0	0	0	0	0	0	8	11	14	6	0	1	0	0	0	0	40
38 - 38.99	0	0	0	0	0	0	0	1	6	9	3	1	0	0	0	0	0	20
39 - 39.99	0	0	0	0	0	0	0	1	3	5	3	5	0	0	0	0	0	17
40 - 40.99	0	0	0	0	0	0	0	0	3	6	7	2	1	0	0	0	0	19
41 - 41.99	0	0	0	0	0	0	0	1	0	2	3	1	1	0	0	0	0	8
42 - 42.99	0	0	0	0	0	0	0	0	0	1	1	1	3	1	0	0	0	7
43 - 43.99	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	0	6
44 - 44.99	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	1	4
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	1	0	5
46 - 46.99	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Totals	7	33	104	49	64	57	38	71	67	68	43	21	10	6	4	2	1	645

Table 4. The number of striped bass assigned to each total length-at-age category for 487 fish sampled for scale age determination in Virginia waters of Atlantic during 2008.

Interval	Age													
	5	6	7	8	9	10	11	12	13	14	15	16	17	20	Totals
27 - 27.99	0	0	2	2	1	0	0	0	0	0	0	0	0	0	5
28 - 28.99	2	1	15	9	6	0	0	0	0	0	0	0	0	0	33
29 - 29.99	4	7	22	6	8	2	0	2	0	0	0	0	0	0	51
30 - 30.99	2	9	19	12	4	1	2	2	0	0	0	0	0	0	51
31 - 31.99	2	2	11	8	2	3	2	2	0	0	0	0	0	0	32
32 - 32.99	0	0	8	4	6	3	2	1	0	0	0	0	0	0	24
33 - 33.99	0	0	3	7	4	3	2	2	1	0	0	0	0	0	22
34 - 34.99	0	0	0	3	4	7	3	3	2	0	1	0	0	0	23
35 - 35.99	0	0	1	5	2	10	8	2	2	3	0	1	0	0	34
36 - 36.99	0	0	2	4	3	10	10	9	7	1	0	0	0	0	46
37 - 37.99	0	0	0	1	5	6	13	13	10	5	0	0	0	0	53
38 - 38.99	0	0	0	0	1	3	12	10	8	2	1	0	0	0	37
39 - 39.99	0	0	0	0	0	2	10	11	6	4	0	0	0	0	33
40 - 40.99	0	0	0	0	0	2	2	5	5	6	2	0	0	0	22
41 - 41.99	0	0	0	0	0	0	1	2	0	0	1	1	1	0	6
42 - 42.99	0	0	0	0	0	0	0	0	2	2	0	1	0	0	5
43 - 43.99	0	0	0	0	0	0	0	1	0	1	1	1	0	0	4
44 - 44.99	0	0	0	0	0	0	0	1	0	0	2	0	0	0	3
45 - 45.99	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
Totals	10	19	83	61	46	52	67	66	43	25	8	5	1	1	487

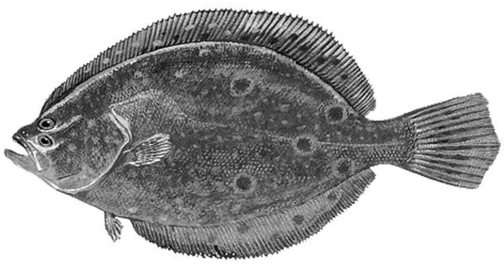
Table 5. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for striped bass sampled in Chesapeake Bay of Virginia during 2008.

	Age																
Interval	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**22**
17 - 17.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 - 18.99	0	0.214	0.429	0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0.056	0.333	0.472	0.056	0.083	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0.125	0.625	0.167	0.083	0	0	0	0	0	0	0	0	0	0	0	0
21 - 21.99	0.03	0.152	0.545	0.182	0.091	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0.125	0.583	0.208	0.042	0	0.042	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0.069	0.103	0.517	0.138	0.034	0.138	0	0	0	0	0	0	0	0	0	0	0
24 - 24.99	0	0.059	0.294	0.176	0.294	0.059	0.088	0.029	0	0	0	0	0	0	0	0	0
25 - 25.99	0	0.034	0.241	0.241	0.172	0.207	0	0.034	0.069	0	0	0	0	0	0	0	0
26 - 26.99	0.036	0.036	0.071	0.179	0.286	0.214	0	0.107	0.036	0.036	0	0	0	0	0	0	0
27 - 27.99	0	0	0	0.045	0.545	0.182	0.136	0	0.091	0	0	0	0	0	0	0	0
28 - 28.99	0	0	0	0.097	0.161	0.29	0	0.258	0.129	0	0.032	0	0	0	0.032	0	0
29 - 29.99	0	0	0	0.062	0.188	0.188	0.25	0.062	0.125	0.062	0.062	0	0	0	0	0	0
30 - 30.99	0	0	0	0	0.167	0.222	0.167	0.111	0.111	0.111	0.056	0.056	0	0	0	0	0
31 - 31.99	0	0	0	0	0.211	0.263	0.105	0.158	0	0.105	0	0.105	0	0.053	0	0	0
32 - 32.99	0	0	0	0	0.095	0.238	0.048	0.381	0.048	0.095	0.095	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0.043	0.13	0.261	0.261	0.087	0.043	0.043	0.087	0	0.043	0	0	0
34 - 34.99	0	0	0	0	0.031	0.188	0.125	0.25	0.25	0.031	0.031	0.031	0.062	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0.265	0.294	0.206	0.088	0.088	0.059	0	0	0	0	0
36 - 36.99	0	0	0	0	0	0	0.043	0.196	0.261	0.37	0.13	0	0	0	0	0	0
37 - 37.99	0	0	0	0	0	0	0	0.2	0.275	0.35	0.15	0	0.025	0	0	0	0
38 - 38.99	0	0	0	0	0	0	0	0.05	0.3	0.45	0.15	0.05	0	0	0	0	0
39 - 39.99	0	0	0	0	0	0	0	0.059	0.176	0.294	0.176	0.294	0	0	0	0	0
40 - 40.99	0	0	0	0	0	0	0	0	0.158	0.316	0.368	0.105	0.053	0	0	0	0
41 - 41.99	0	0	0	0	0	0	0	0.125	0	0.25	0.375	0.125	0.125	0	0	0	0
42 - 42.99	0	0	0	0	0	0	0	0	0	0.143	0.143	0.143	0.429	0.143	0	0	0
43 - 43.99	0	0	0	0	0	0	0	0	0	0.167	0.167	0.167	0.167	0.333	0	0	0
44 - 44.99	0	0	0	0	0	0	0	0	0.25	0	0.5	0	0	0	0	0	0.25
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0.4	0.2	0.2	0	0.2	0
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0.5	0
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Table 6. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for striped bass sampled in Virginia waters of Atlantic during 2008.

	Age													
Interval	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**20**
27 - 27.99	0	0	0.4	0.4	0.2	0	0	0	0	0	0	0	0	0
28 - 28.99	0.061	0.03	0.455	0.273	0.182	0	0	0	0	0	0	0	0	0
29 - 29.99	0.078	0.137	0.431	0.118	0.157	0.039	0	0.039	0	0	0	0	0	0
30 - 30.99	0.039	0.176	0.373	0.235	0.078	0.02	0.039	0.039	0	0	0	0	0	0
31 - 31.99	0.062	0.062	0.344	0.25	0.062	0.094	0.062	0.062	0	0	0	0	0	0
32 - 32.99	0	0	0.333	0.167	0.25	0.125	0.083	0.042	0	0	0	0	0	0
33 - 33.99	0	0	0.136	0.318	0.182	0.136	0.091	0.091	0.045	0	0	0	0	0
34 - 34.99	0	0	0	0.13	0.174	0.304	0.13	0.13	0.087	0	0.043	0	0	0
35 - 35.99	0	0	0.029	0.147	0.059	0.294	0.235	0.059	0.059	0.088	0	0.029	0	0
36 - 36.99	0	0	0.043	0.087	0.065	0.217	0.217	0.196	0.152	0.022	0	0	0	0
37 - 37.99	0	0	0	0.019	0.094	0.113	0.245	0.245	0.189	0.094	0	0	0	0
38 - 38.99	0	0	0	0	0.027	0.081	0.324	0.27	0.216	0.054	0.027	0	0	0
39 - 39.99	0	0	0	0	0	0.061	0.303	0.333	0.182	0.121	0	0	0	0
40 - 40.99	0	0	0	0	0	0.091	0.091	0.227	0.227	0.273	0.091	0	0	0
41 - 41.99	0	0	0	0	0	0	0.167	0.333	0	0	0.167	0.167	0.167	0
42 - 42.99	0	0	0	0	0	0	0	0	0.4	0.4	0	0.2	0	0
43 - 43.99	0	0	0	0	0	0	0	0.25	0	0.25	0.25	0.25	0	0
44 - 44.99	0	0	0	0	0	0	0	0.333	0	0	0.667	0	0	0
45 - 45.99	0	0	0	0	0	0	0	0	0	1	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5

Chapter 11
Summer Flounder



Paralichthys dentatus

INTRODUCTION

We aged a total of 765 summer flounder, *Paralichthys dentatus*, using their scales collected by the VMRC's Biological Sampling Program in 2008. Of 765 aged fish, 384 and 381 fish were collected in Chesapeake Bay (bay fish) and Atlantic waters (ocean fish) of Virginia, respectively. The average age for the bay fish was 2.7 years with a standard deviation of 1.4 and a standard error of 0.07. Nine age classes (0 to 8) were represented in the bay fish, comprising fish from the 2000 to 2008 year classes. The year class of 2006 (45%) was dominant in the bay fish sample in 2008 The average age for the ocean fish was 4 years with a standard deviation of 1.9 and a standard error of 0.1. Ten age classes (1 to 10) were represented in the ocean fish, comprising fish from the 1998 to 2007 year classes. The year class of 2004 (25%) was dominant in the ocean fish sample in 2008 followed by the year classes of 2006 (20%) and 2005 (17%). We also aged a total of 157 fish using their otoliths in addition to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were to one another (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing summer flounder collected in both Chesapeake Bay and Atlantic waters of Virginia in 2008, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing summer flounder in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of summer flounder collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of summer flounder used by VMRC to estimate length distribution of the caches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to decide A (number of fish) is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Sagittal otoliths (hereafter, referred to as "otoliths") and scales were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and scales were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

Preparation —

Scales – Summer flounder scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and uniform size. We selected a range of five to ten preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure:	12000 to 15000 psi
Temperature:	Room temperature
Time:	7 minutes

Otoliths – The left otoliths of summer flounder are symmetrical in relation to the otolith nucleus, while right otoliths are asymmetrical. The right sagittal otolith was mounted with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three inch diameter, Norton® Diamond Grinding Wheels (hereafter referred to as "blades"), separated by a stainless steel spacer of 0.4mm (diameter 2.5"). The otolith was positioned so that the blades straddled each side of the otolith focus mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the otolith thin-section was placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400^{o}C. Baking time was dependent on otolith size and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx® mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, summer flounder otolith deposition occurs between January and April (Bolz et al. 1999). A summer flounder captured between January 1 and April 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of April 30, the period of annulus formation, which would be noted as 4 + 4.

Summer flounder scales are also considered to have a deposition period of January through April (Bolz et al. 1999), and age class assignment using these hard-parts is conducted in the same way as otoliths.

All summer flounder samples (scale pressings and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Scales - We determined fish age by viewing the acetate impressions of scales (Figure 1) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses.

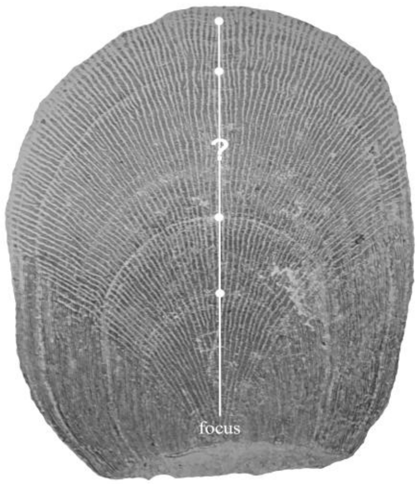


Figure 1. Sclae impression of a 590 mm female summer flounder collected in November and aged as 4 years old with scales. The question mark is located at a possible "3rd" annulus.

Annuli on summer flounder scales are primarily identified by the presence of crossing over of circuli. Crossing over is most evident on the lateral margins near the posterior/anterior interface of the scale. Here compressed circuli (annulus) “cross over” the deposited circuli of the previous year’s growth. Typically the annulus will protrude partially into the ctenii of the posterior field, but not always.

Following the annulus up into the anterior field of the scale reveals a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are associated with the disruption of circuli. This pattern should be continuous throughout the entire anterior field of the scale. Locating the first annulus can be difficult due to latitudinal differences in growth rates and changes in the size of the first annulus due to a protracted spawning season. We consider the first annulus to be the first continuous crossing over event formed on the scale.

Otoliths – All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 2).

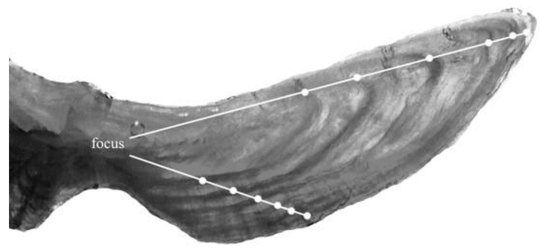


Figure 2. Otolith section from a 590 mm, 6-year-old female summer flounder collected in November. Same fish as Figure 1.

Summer flounder otoliths are composed of visually distinct summer and winter growth zones. By convention, an annulus is identified as the narrow opaque zone, or winter growth band. With sectioned otoliths, to be considered a true annulus, these growth bands must be rooted in the sulcus and able to be followed, without interruption to the distal surface of the otolith. The annuli in summer flounder have a tendency to split as they advance towards the distal surface. As a result, it is critical that the reading path proceeds in a direction from the sulcus to the proximal surface. The first annulus is located directly below the focus and near the upper portion of the sulcal groove. The distance from the focus to the first year is moderate, with translucent zone deposition gradually becoming smaller as consecutive annuli are deposited towards the outer edge.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between scale and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 385 for ageing the bay summer flounder in 2008, ranging in length interval from 9 to 28 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 2 to the largest CV of 23% for age 6 of the bay fish. We randomly selected and aged 384 fish from 462 summer flounder collected by VMRC in Chesapeake Bay in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 34 fish mainly in the very small and large length intervals (Table 1), as a result, the precision for the estimates of the majority of age categories would not be influenced significantly.

We estimated a sample size of 385 for ageing the ocean summer flounder in 2008, ranging in length interval from 12 to 30 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 8% for age 3 to the largest CV of 24% for age 8 of the ocean fish. We randomly selected and aged 381 fish from 449 summer flounder collected by VMRC in the Atlantic waters of Virginia in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 58 fish mainly from the small and large length intervals (Table 2), as a result, the precision for the estimates of all age groups would not be influenced significantly.

Scales — The measurement of reader self-precision was very good for Reader 1 and poor for Reader 2. There is no significant difference between the first and second readings for Reader 1 with an agreement of 90% and a CV of 1.7% (test of symmetry: $\chi^2 = 5$, df = 5, $P = 0.4159$). There is no significant difference between the first and second readings for Reader 2 with an agreement of 60% and a CV of 10.1% (test of symmetry: $\chi^2 = 14.67$, df = 8, $P = 0.066$). There was an evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 65% and a CV of 9.9% (test of symmetry: $\chi^2 = 37$, df = 22, $P < 0.0236$) (Figure 3).

There is no time-series bias for both readers. The age readings of 80% fish by Reader 1 in 2008 had an agreement with those fish aged in 2000 with a CV of 4.4% (test of symmetry: $\chi^2 = 4$, df = 5, $P = 0.5494$). The age readings of 76% fish by

Reader 2 in 2008 had an agreement with those fish aged in 2000 with a CV of 5.3% (test of symmetry: $\chi^2 = 12$, df = 7, P = 0.1006).

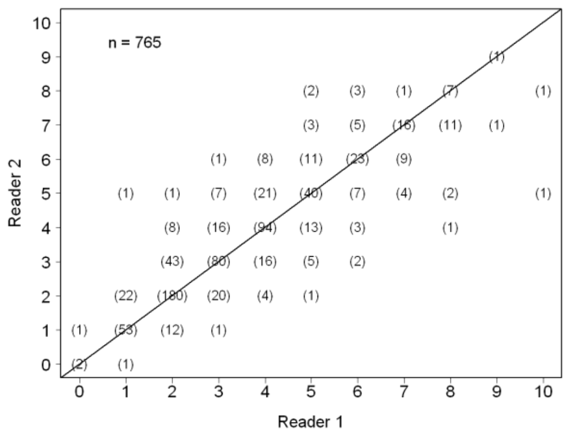


Figure 3. Between-reader comparison of scale age estimates for summer flounder collected in Chesapeake Bay and Virginia waters of Atlantic in 2008.

Of the 384 bay summer flounder aged with scales, 9 age classes (0 to 8) were represented (Table 3). The average age for the sample was 2.7 years. The standard deviation and standard error were 1.4 and 0.07, respectively. Year-class data indicates that recruitment into the fishery in Chesapeake Bay begins at age 0, which corresponds to the 2008 year-class for summer flounder caught in 2008. The year class of 2006 (45%) summer flounder was dominated in the sample in 2008. The sex ratio of male to female was 1:23.25 for the bay fish (Figure 4).

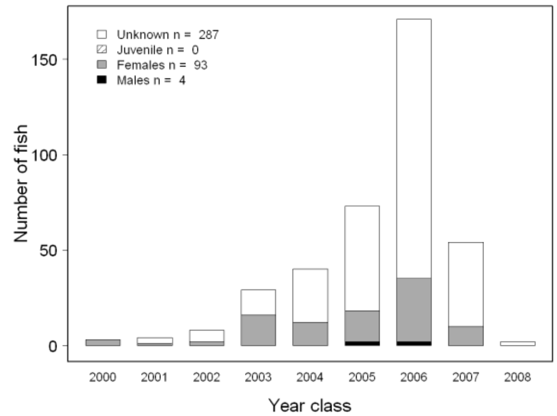


Figure 4. Year-class frequency distribution for summer flounder collected in Chesapeake Bay of Virginia for ageing in 2008. Distribution is broken down by sex and estimated using scale ages. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Of the 381 ocean summer flounder aged with scales, 10 age classes (1 to 10) were represented (Table 4). The average age for the sample was 4 years. The standard deviation and standard error were 1.9 and 0.1, respectively. Year-class data indicates that recruitment into the fishery in the Atlantic waters of Virginia begins at age 1, which corresponds to the 2007 year-class for summer flounder caught in 2008. The year class of 2004 (25%) summer flounder was dominated in the sample in 2008 followed by the year class of 2006 (20%) and 2005 (17%). The sex ratio of male to female was 1:80 for the ocean fish (Figure 5).

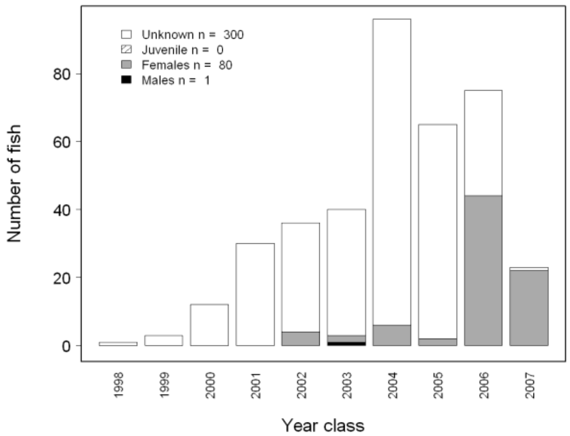


Figure 5. Year-class frequency distribution for summer flounder collected in Virginia waters of the Atlantic for ageing in 2008. Distribution is broken down by sex and estimated using scale ages. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

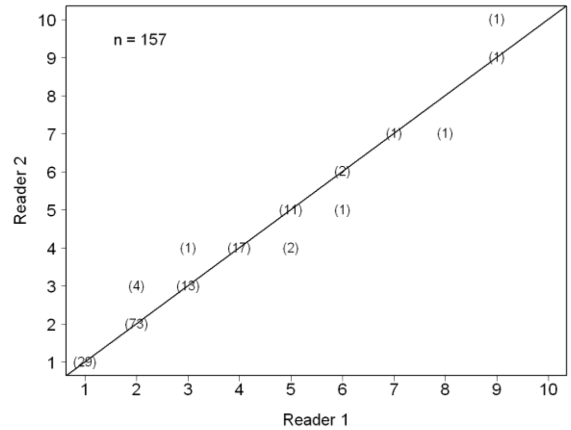


Figure 6. Between-reader comparison of otolith age estimates for summer flounder collected in Chesapeake Bay and Virginia waters of Atlantic in 2008.

Otoliths — The measurement of reader self-precision was very good for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV of 0.9% and an agreement of 98% (test of symmetry: $\chi^2 = 1$, df = 1, $P = 0.3173$). There is no significant difference between the first and second readings for Reader 2 with a CV = 2.7% and an agreement of 90% (test of symmetry: $\chi^2 = 3$, df = 5, $P = 0.5578$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 94% and a CV of 1.2% (test of symmetry: $\chi^2 = 10$, df = 6, $P = 0.1247$) (Figure 6).

There is no time-series bias for both readers. Reader 1 had an agreement of 92% with the fish aged in 2003 with a CV of 1.4% (test of symmetry: $\chi^2 = 4$, df = 3, $P = 0.2615$). Reader 2 had an agreement of 86% with the fish aged in 2003 with a CV of 3.6% (test of symmetry: $\chi^2 = 7$, df = 4, $P = 0.1359$).

Of 157 fish aged with otoliths, 10 age classes (1 to 10) were represented for summer flounder. The average age for the sample was 2.6 years. The standard deviation and standard error were 1.6 and 0.13, respectively.

Comparison of Scale and Otolith Ages — We aged 157 summer flounder using scales and otoliths. There was no evidence of systematic disagreement between otolith and scale ages (test of symmetry: $\chi^2 = 8.87$, df = 11, $P = 0.6342$) with an average CV of 5.6%. There was an agreement of 81% between scale and otolith ages. Scales were assigned a lower and higher age than otoliths for 10% and 9% of the fish, respectively (Figure 7). Although the symmetric test didn't show any evidence of systematic disagreement between otoliths and scale ages, the 1:1 equivalence plot indicated that that scale were generally assigned lower ages for older fish than otoliths age estimates (Figure 8).

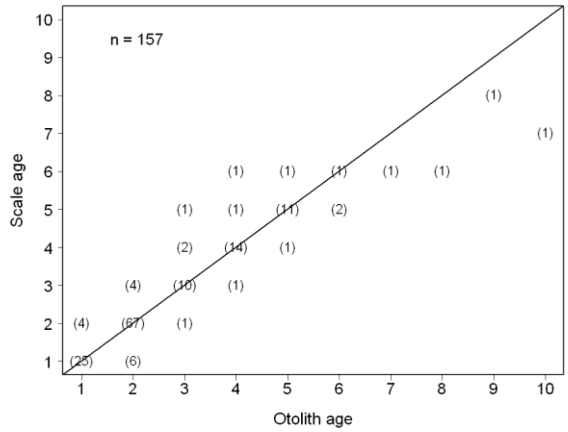


Figure 7. Comparison of scale and otolith age estimates for summer flounder collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

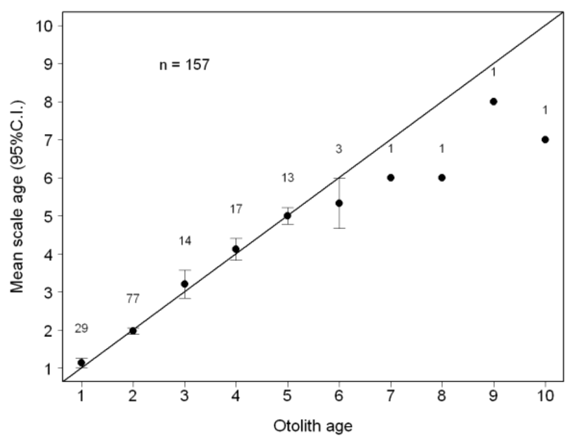


Figure 8. Age-bias plot for summer flounder scale and otolith age estimates in 2008.

Age-Length-Key (ALK) —We developed an ALK for both bay (Table 5) and ocean fish (Table 6) using scale ages, separately. The ALK can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Bolz, G., R. Monaghan, K. Lang, R. Gregory, and J. Burnett. 1999. Proceedings of the summer flounder ageing workshop, 1-2 February 1999, Woods Hole, MA. . NOAA Tech. Memo, in press.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford Univeristy Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of summer flounder collected in the Chesapeake Bay of Virginia in 2008 and scale-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
9 - 9.99	5	0	0	5
10 - 10.99	5	0	0	5
11 - 11.99	5	0	0	5
12 - 12.99	5	3	3	2
13 - 13.99	13	10	10	3
14 - 14.99	66	74	72	0
15 - 15.99	55	71	59	0
16 - 16.99	47	89	48	0
17 - 17.99	44	74	54	0
18 - 18.99	35	42	40	0
19 - 19.99	27	31	30	0
20 - 20.99	18	20	20	0
21 - 21.99	15	14	14	1
22 - 22.99	10	14	14	0
23 - 23.99	10	8	8	2
24 - 24.99	5	5	5	0
25 - 25.99	5	5	5	0
26 - 26.99	5	1	1	4
27 - 27.99	5	1	1	4
28 - 28.99	5	0	0	5
Totals	385	462	384	36

Table 2. Number of summer flounder collected in Virginia waters of Atlantic in 2008 and scale-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
12 - 12.99	5	0	0	5
13 - 13.99	13	0	0	13
14 - 14.99	37	27	27	10
15 - 15.99	57	64	62	0
16 - 16.99	58	79	62	0
17 - 17.99	48	41	41	7
18 - 18.99	31	54	38	0
19 - 19.99	20	45	29	0
20 - 20.99	19	24	23	0
21 - 21.99	12	31	16	0
22 - 22.99	16	26	25	0
23 - 23.99	15	19	19	0
24 - 24.99	14	20	20	0
25 - 25.99	12	14	14	0
26 - 26.99	8	3	3	5
27 - 27.99	5	0	0	5
28 - 28.99	5	1	1	4
29 - 29.99	5	1	1	4
30 - 30.99	5	0	0	5
Totals	385	449	381	58

Table 3. The number of summer flounder assigned to each total length-at-age category for 384 fish sampled for scale age determination in Chesapeake Bay of Virginia during 2008.

	Age									
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Totals**
12 - 12.99	0	3	0	0	0	0	0	0	0	3
13 - 13.99	0	4	5	1	0	0	0	0	0	10
14 - 14.99	2	14	46	9	1	0	0	0	0	72
15 - 15.99	0	11	35	11	2	0	0	0	0	59
16 - 16.99	0	7	27	11	2	0	1	0	0	48
17 - 17.99	0	7	29	11	5	2	0	0	0	54
18 - 18.99	0	4	17	11	5	3	0	0	0	40
19 - 19.99	0	1	6	9	7	6	1	0	0	30
20 - 20.99	0	2	2	4	8	4	0	0	0	20
21 - 21.99	0	0	4	4	2	3	1	0	0	14
22 - 22.99	0	0	0	1	3	7	2	1	0	14
23 - 23.99	0	1	0	0	3	1	2	1	0	8
24 - 24.99	0	0	0	1	1	2	0	1	0	5
25 - 25.99	0	0	0	0	1	1	1	1	1	5
26 - 26.99	0	0	0	0	0	0	0	0	1	1
27 - 27.99	0	0	0	0	0	0	0	0	1	1
Totals	2	54	171	73	40	29	8	4	3	384

Table 4. The number of summer flounder assigned to each total length-at-age category for 381 fish sampled for scale age determination in Virginia waters of Atlantic during 2008.

	Age										
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Totals**
14 - 14.99	2	11	13	1	0	0	0	0	0	0	27
15 - 15.99	9	21	21	10	1	0	0	0	0	0	62
16 - 16.99	7	14	15	22	3	1	0	0	0	0	62
17 - 17.99	0	13	7	13	7	1	0	0	0	0	41
18 - 18.99	3	12	4	14	3	0	2	0	0	0	38
19 - 19.99	2	3	2	15	6	1	0	0	0	0	29
20 - 20.99	0	1	1	9	5	2	3	1	1	0	23
21 - 21.99	0	0	0	3	4	8	1	0	0	0	16
22 - 22.99	0	0	1	4	7	6	5	1	1	0	25
23 - 23.99	0	0	1	3	2	8	3	2	0	0	19
24 - 24.99	0	0	0	1	2	5	7	4	1	0	20
25 - 25.99	0	0	0	1	0	4	6	3	0	0	14
26 - 26.99	0	0	0	0	0	0	2	1	0	0	3
28 - 28.99	0	0	0	0	0	0	0	0	0	1	1
29 - 29.99	0	0	0	0	0	0	1	0	0	0	1
Totals	23	75	65	96	40	36	30	12	3	1	381

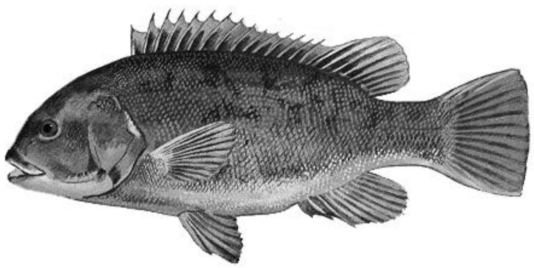
Table 5. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for summer flounder sampled in Chesapeake Bay of Virginia during 2008.

	Age								
Interval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12 - 12.99	0	1	0	0	0	0	0	0	0
13 - 13.99	0	0.4	0.5	0.1	0	0	0	0	0
14 - 14.99	0.028	0.194	0.639	0.125	0.014	0	0	0	0
15 - 15.99	0	0.186	0.593	0.186	0.034	0	0	0	0
16 - 16.99	0	0.146	0.562	0.229	0.042	0	0.021	0	0
17 - 17.99	0	0.13	0.537	0.204	0.093	0.037	0	0	0
18 - 18.99	0	0.1	0.425	0.275	0.125	0.075	0	0	0
19 - 19.99	0	0.033	0.2	0.3	0.233	0.2	0.033	0	0
20 - 20.99	0	0.1	0.1	0.2	0.4	0.2	0	0	0
21 - 21.99	0	0	0.286	0.286	0.143	0.214	0.071	0	0
22 - 22.99	0	0	0	0.071	0.214	0.5	0.143	0.071	0
23 - 23.99	0	0.125	0	0	0.375	0.125	0.25	0.125	0
24 - 24.99	0	0	0	0.2	0.2	0.4	0	0.2	0
25 - 25.99	0	0	0	0	0.2	0.2	0.2	0.2	0.2
26 - 26.99	0	0	0	0	0	0	0	0	1
27 - 27.99	0	0	0	0	0	0	0	0	1

Table 6. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for summer flounder sampled in Virginia waters of Atlantic during 2008.

	Age									
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
14 - 14.99	0.074	0.407	0.481	0.037	0	0	0	0	0	0
15 - 15.99	0.145	0.339	0.339	0.161	0.016	0	0	0	0	0
16 - 16.99	0.113	0.226	0.242	0.355	0.048	0.016	0	0	0	0
17 - 17.99	0	0.317	0.171	0.317	0.171	0.024	0	0	0	0
18 - 18.99	0.079	0.316	0.105	0.368	0.079	0	0.053	0	0	0
19 - 19.99	0.069	0.103	0.069	0.517	0.207	0.034	0	0	0	0
20 - 20.99	0	0.043	0.043	0.391	0.217	0.087	0.13	0.043	0.043	0
21 - 21.99	0	0	0	0.188	0.25	0.5	0.062	0	0	0
22 - 22.99	0	0	0.04	0.16	0.28	0.24	0.2	0.04	0.04	0
23 - 23.99	0	0	0.053	0.158	0.105	0.421	0.158	0.105	0	0
24 - 24.99	0	0	0	0.05	0.1	0.25	0.35	0.2	0.05	0
25 - 25.99	0	0	0	0.071	0	0.286	0.429	0.214	0	0
26 - 26.99	0	0	0	0	0	0	0.667	0.333	0	0
28 - 28.99	0	0	0	0	0	0	0	0	0	1
29 - 29.99	0	0	0	0	0	0	1	0	0	0

Chapter 12
Tautog



Tautoga onitis

INTRODUCTION

We aged a total of 134 tautog, *Tautoga onitis*, using their opercula collected by the VMRC's Biological Sampling Program in 2008. Of 134 aged fish, 120 and 14 fish were collected in Chesapeake Bay (bay fish) and the Atlantic waters (ocean fish) of Virginia, respectively. The average age of the bay fish was 4.3 years with a standard deviation of 1.3 and a standard error of 0.12. Seven age classes (2 to 8) were represented in the bay fish, comprising fish from the 2000 to 2006 year classes. The year class of 2004 (31%) was dominant in the bay fish sample in 2008 followed by the year classes of 2003 (28%). The average age for the ocean fish was 6.9 years with a standard deviation of 1.8 and a standard error of 0.48. Six age classes (age 3 and 5 to 9) were represented in the ocean fish, comprising fish from the 1999 to 2003, and 2005 year classes. We also aged a total of 129 fish using their otoliths in addition to ageing their opercula. The otolith ages were compared to the operculum ages to examine how close both ages were to one another (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing tautog collected in both Chesapeake Bay and Atlantic waters of Virginia in 2008, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing tautog in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of tautog collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of tautog used by VMRC to estimate length distribution of the caches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to decide A (number of fish) is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Sagittal otoliths (hereafter, refer to as “otoliths”) and opercula were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC’s collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and opercula were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

Preparation —

Opercula Tautog opercula were boiled for several minutes to remove any attached skin and muscle tissue. After boiling, opercula were examined to determine whether they were collected whole or in some way damaged. Opercula were allowed to dry and finally stored in new labeled coin envelopes.

Otoliths Due to their fragility, we used our embedding and thin-sectioning method to prepare tautog otoliths for age determination. To start, a series of 14 mm x 5 mm x 3 mm wells (Ladd Industries silicon rubber mold) were pre-filled to half-volume with Loctite® 349 adhesive and permitted to cure for 24 hours until solidified. The wells were then filled to capacity with fresh, non-cured Loctite® 349 adhesive, at which point the otoliths could be inserted into the wells, suspended within a stable embedding atmosphere before sectioning. Otoliths were baked before embedment in the Loctite® 349 adhesive to produce better contrast of opaque and translucent zones within the matrix. Each otolith was baked in a Thermolyne 1400 furnace at 400°C for one to two minutes until it turned a medium brown color (caramel). The baked otoliths were inserted into the fresh Loctite® 349 adhesive, distal side up, with the long axis of the otolith exactly parallel with the long axis of the mold well. Once the otoliths were properly oriented, the mold was placed under UV light and left to solidify overnight. Once dry, each embedded otolith was removed from the mold and mounted with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter “thin-section) was then removed from the marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, three inch diameter, Norton® Diamond Grinding Wheels, separated by a stainless steel spacer of 0.4mm (diameter 2.5”). The otolith was positioned so that the blades straddled each side of the focus marked by pencil. The glass slide was adjusted to ensure that the blades were exactly perpendicular to the long axis of the otolith. The otolith thin-section was viewed under a stereo microscope to determine which side (cut surface) of the otolith was closer to the focus. The otolith thin-section was mounted best-side up onto a glass slide with Flo-texx® mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of dark bands in the otolith.

If the fish is captured between January 1 and the end of the species specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the dark band deposition period, is interpreted as being toward the next age class.

For example, tautog otolith deposition occurs between May and July (Hostetter and Munroe 1993). A summer flounder captured between January 1 and July 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of July 31, the period of annulus formation, which would be noted as 4 + 4.

Tautog opercula are also considered to have a deposition period of May through July (Hostetter and Munroe 1993), and age class assignment using these hard-parts is conducted in the same way as otoliths.

All tautog samples (prepared opercula and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. Opercula were aged on a light table with no magnification (Figure 1).

Figure 1. Operculum from a 13 year-old male tautog.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 2).

Figure 2. Otolith section from a 13 year-old male tautog. Same fish as Figure 1.

When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between operculum and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 393 for ageing the bay tautog in 2008, ranging in length interval from 9 to 25 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 8% for age 3 to the largest CV of 25% for age 1 of the bay fish. We aged all 116 tautog who had both total lengths and opercula collected by VMRC in Chesapeake Bay in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 277 fish from among the small, medium, and large length intervals (Table 1), as a result, the precision for the estimates of all age groups would be influenced significantly.

We estimated a sample size of 376 for ageing the ocean tautog in 2008, ranging in length interval from 8 to 30 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 9% for age 5 to the largest CV of 25% for age 2 of the ocean fish. We aged all 14 tautog collected by VMRC in Atlantic waters of Virginia in 2008. We fell short in our over-all collections for this optimal length-class sampling estimate by 362 fish from among the small, medium, and large length intervals (Table 2), as a result, the precision for the estimates of all age groups would be influenced significantly.

Opercula — The measurement of reader self-precision was good for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV of 3.5% and an agreement of 76% (test of symmetry: $\chi^2 = 8$, df = 8, P = 0.4335). There is no significant difference between the first and second readings for Reader 2 with a CV of 4.4% an agreement of 72% (test of symmetry: $\chi^2 = 12$, df = 9, P = 0.2133). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with a CV of 5.2% an agreement of 70% (test of symmetry: $\chi^2 = 10.33$, df = 10, P = 0.4118) (Figure 3).

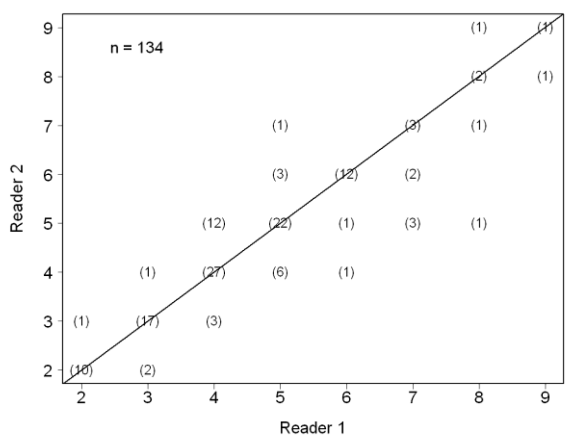


Figure 3. Between-reader comparison of operculum age estimates for tautog collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

There is no time-series bias for both readers. The age readings of 58% fish by Reader 1 in 2008 had an agreement with those fish aged in 2003 with a CV of 6% (test of symmetry: $\chi^2 = 7.5$, df = 7, P = 0.3787). The age readings of 72% fish by Reader 2 in 2008 had an agreement with those fish aged in 2003 with a CV of 4.4% (test of symmetry: $\chi^2 = 11$, df = 9, P = 0.2757).

Of the 120 bay tautog aged with opercula, 7 age classes (2 to 8) were represented (Table 3). The average age for the sample was 4.3 years. The standard deviation and standard error were 1.3 and 0.12, respectively. Year-class data indicates that recruitment into the fishery in Chesapeake Bay begins at age 2, which corresponds to the 2006 year-class for tautog caught in 2008. The year class of 2004 (31%) tautog was dominated in the sample in 2008 followed by 2003 (28%). The sex ratio of male to female was 1:1.58 for the bay fish (Figure 4).

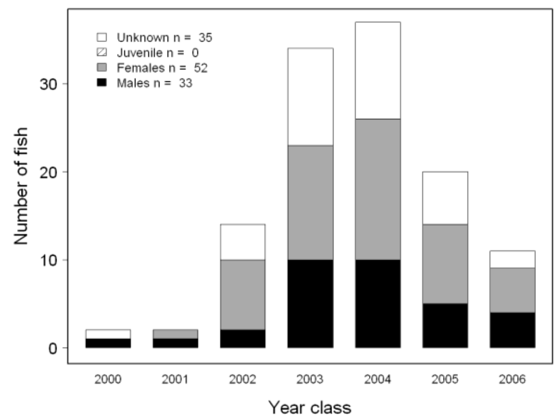


Figure 4. Year-class frequency distribution for tautog collected in Chesapeake Bay of Virginia for ageing in 2008. Distribution is broken down by sex and estimated using operculum ages. "Unknown" is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Of the 14 ocean tautog aged with opercula, 6 age classes (3, 5 to 9) were represented (Table 4). The average age for the sample was 6.9 years. The standard deviation and standard error were 1.8 and 0.48, respectively. Year-class data indicates that recruitment into the fishery in Atlantic waters of Virginia begins at age 3, which corresponds to the 2005 year-class for tautog caught in 2008. The sex ratio of male to female was 1:2.5 for the ocean fish (Figure 5).

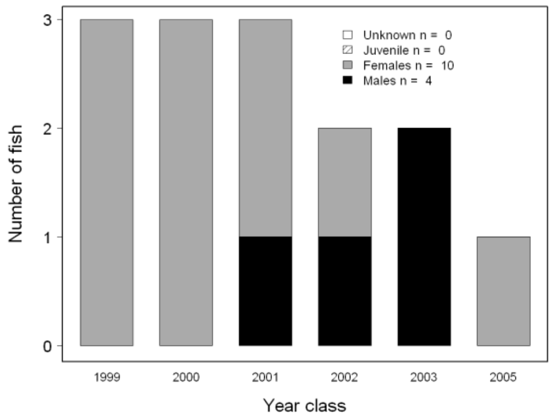


Figure 5. Year-class frequency distribution for tautog collected in Virginia waters of Atlantic for ageing in 2008. Distribution is broken down by sex and estimated using operculum ages. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Otoliths — The measurement of reader self-precision was very good for both readers. There is no significant difference between the first and second readings for Reader 1 with a CV of 1.4% and an agreement of 92% (test of symmetry: $\chi^2 = 4$, df = 4, $P = 0.4060$). There is no significant difference between the first and second readings for Reader 2 with a CV of 2.5% and an agreement of 84% (test of symmetry: $\chi^2 = 6$, df = 6, $P = 0.4232$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 95% and a CV of 0.9% (test of symmetry: $\chi^2 = 7$, df = 5, $P = 0.2206$) (Figure 6).

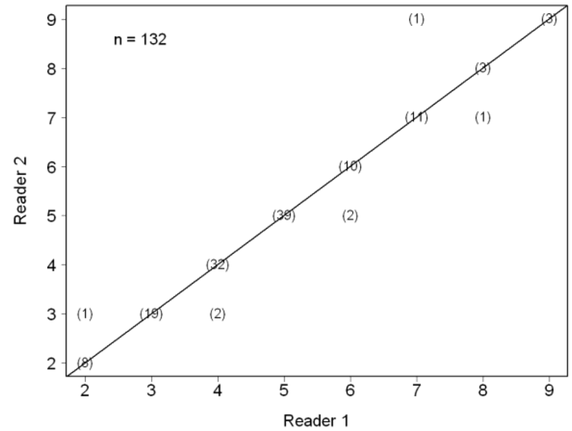


Figure 6. Between-reader comparison of otolith age estimates for tautog collected in Chesapeake Bay and Virginia waters of Atlantic in 2008.

There is no time-series bias for both readers. Reader 1 had an agreement of 92% with the fish aged in 2003 with a CV of 1% (test of symmetry: $\chi^2 = 4$, df = 2, $P = 0.1353$). Reader 2 had an agreement of 88% with the fish aged in 2003 with a CV of 1.3% (test of symmetry: $\chi^2 = 3.33$, df = 2, $P = 0.1889$).

Of 129 fish aged with otoliths, 8 age classes (2 to 9) were represented. The average age for the sample was 4.7 years. The standard deviation and standard error were 1.6 and 0.14, respectively.

Comparison of Operculum and Otolith Ages — We aged 128 tautog using both their opercula and otoliths. There was no evidence of systematic disagreement between otolith and operculum ages (test of symmetry: $\chi^2 = 12.29$, df = 11, $P = 0.3426$) with an average CV of 7.3%. There was an agreement of 64% between operculum and otolith ages whereas opercula were assigned a lower and higher age than otoliths for 23% and 13% of the fish, respectively (Figure 7). There was also no evidence of bias between otolith and operculum ages using an age bias plot (Figure 8**)**.

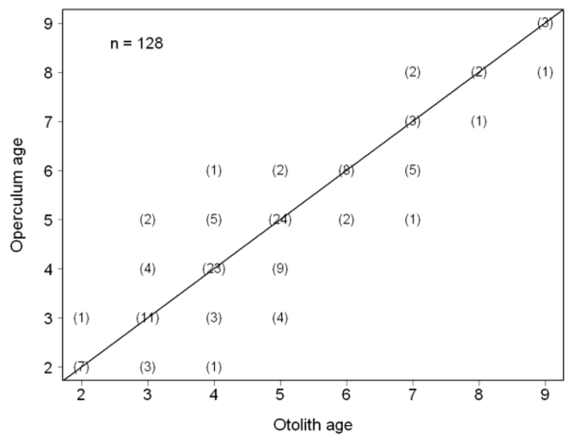


Figure 7. Comparison operculum and otolith age estimates for tautog collected in Chesapeake Bay and Virginia waters of the Atlantic in 2008.

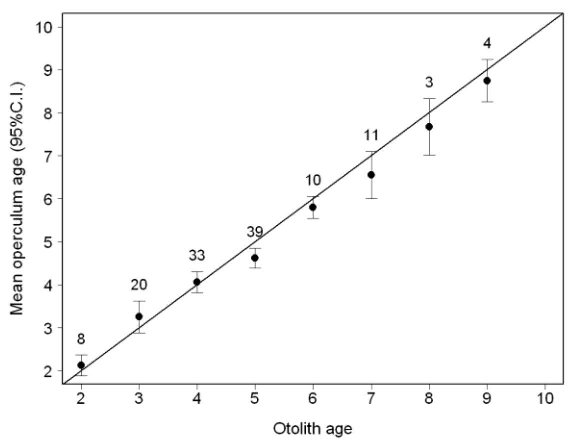


Figure 8. Age-bias plot for tautog operculum and otolith age estimates in 2008.

Age-Length-Key(ALK) — We developed an ALK for both bay (Table 5) and ocean fish (Table 6) using operculum ages, separately. Due to the small samples collected in 2008, we don't recommend to use the ALKs to do the conversion of numbers-at-length in the estimated catch to numbers-at-age.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Hostetter, E. B., and T. A. Munroe. 1993. Age, growth, and reproduction of tautog *Tautoga onitis (Labridae: Perciformes)* from coastal waters of Virginia. Fishery Bulletin 91: 45-64.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

White, G.G., J.E. Kirkley, and J.A. Lucy. 1997. Quantitative assessment of fishing mortality for tautog, *Tautoga onitis*, in Virginia. Preliminary report to the Virginia Marine Recreational Advisory Board and Virginia Marine Resources Commission. Newport News, VA.

Table 1. Number of tautog collected in the Chesapeake Bay of Virginia in 2008 and operculum-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged. There were 2 fish without opercula.

Interval	Target	Collected	Aged	Need
9 - 9.99	5	0	0	5
10 - 10.99	5	0	0	5
11 - 11.99	9	0	0	9
12 - 12.99	10	3	3	7
13 - 13.99	54	10	10	44
14 - 14.99	83	27	26	57
15 - 15.99	66	29	29	37
16 - 16.99	49	20	20	29
17 - 17.99	40	14	14	26
18 - 18.99	25	8	8	17
19 - 19.99	14	3	3	11
20 - 20.99	8	2	2	6
21 - 21.99	5	0	0	5
22 - 22.99	5	1	0	5
23 - 23.99	5	1	1	4
24 - 24.99	5	0	0	5
25 - 25.99	5	0	0	5
Totals	393	118	116	277

Table 2. Number of tautog collected in Virginia waters of Atlantic in 2008 and operculum-aged in each 1-inch length interval. “Target” represents the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and “Need” represents number of fish that were not obtained in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
8 - 8.99	5	0	0	5
9 - 9.99	5	0	0	5
10 - 10.99	5	0	0	5
11 - 11.99	10	0	0	10
12 - 12.99	8	0	0	8
13 - 13.99	49	0	0	49
14 - 14.99	56	0	0	56
15 - 15.99	52	0	0	52
16 - 16.99	46	2	2	44
17 - 17.99	36	2	2	34
18 - 18.99	29	5	5	24
19 - 19.99	18	2	2	16
20 - 20.99	18	2	2	16
21 - 21.99	10	0	0	10
22 - 22.99	7	1	1	6
23 - 23.99	7	0	0	7
24 - 24.99	5	0	0	5
25 - 25.99	5	0	0	5
30 - 30.99	5	0	0	5
Totals	376	14	14	362

Table 3. The number of tautog assigned to each total length-at-age category for 116 fish sampled for operculum age determination in Chesapeake Bay of Virginia during 2008.

	Age							
Interval	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Totals**
12 - 12.99	1	1	1	0	0	0	0	3
13 - 13.99	3	3	3	1	0	0	0	10
14 - 14.99	7	11	7	1	0	0	0	26
15 - 15.99	0	4	10	10	5	0	0	29
16 - 16.99	0	1	7	9	3	0	0	20
17 - 17.99	0	0	4	9	1	0	0	14
18 - 18.99	0	0	1	4	2	0	1	8
19 - 19.99	0	0	1	0	1	1	0	3
20 - 20.99	0	0	0	0	0	1	1	2
23 - 23.99	0	0	0	0	1	0	0	1
Totals	11	20	34	34	13	2	2	116

Table 4. The number of tautog assigned to each total length-at-age category for 14 fish sampled for operculum age determination in Virginia waters of Atlantic during 2008.

	Age						
Interval	**3**	**5**	**6**	**7**	**8**	**9**	**Totals**
16 - 16.99	1	0	0	0	1	0	2
17 - 17.99	0	1	0	0	1	0	2
18 - 18.99	0	0	1	2	0	2	5
19 - 19.99	0	1	0	0	1	0	2
20 - 20.99	0	0	1	0	0	1	2
22 - 22.99	0	0	0	1	0	0	1
Totals	1	2	2	3	3	3	14

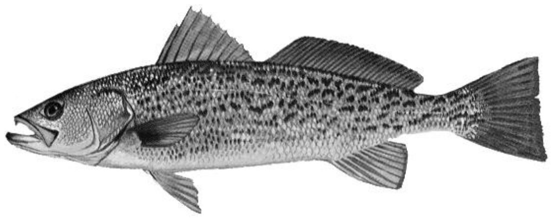
Table 5. Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for tautog sampled in Chesapeake Bay of Virginia during 2008.

	Age						
Interval	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12 - 12.99	0.333	0.333	0.333	0	0	0	0
13 - 13.99	0.3	0.3	0.3	0.1	0	0	0
14 - 14.99	0.269	0.423	0.269	0.038	0	0	0
15 - 15.99	0	0.138	0.345	0.345	0.172	0	0
16 - 16.99	0	0.05	0.35	0.45	0.15	0	0
17 - 17.99	0	0	0.286	0.643	0.071	0	0
18 - 18.99	0	0	0.125	0.5	0.25	0	0.125
19 - 19.99	0	0	0.333	0	0.333	0.333	0
20 - 20.99	0	0	0	0	0	0.5	0.5
23 - 23.99	0	0	0	0	1	0	0

Table 6. Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for tautog sampled in Virginia waters of Atlantic during 2008.

	Age					
Interval	**3**	**5**	**6**	**7**	**8**	**9**
16 - 16.99	0.5	0	0	0	0.5	0
17 - 17.99	0	0.5	0	0	0.5	0
18 - 18.99	0	0	0.2	0.4	0	0.4
19 - 19.99	0	0.5	0	0	0.5	0
20 - 20.99	0	0	0.5	0	0	0.5
22 - 22.99	0	0	0	1	0	0

Chapter 13
Weakfish



Cynoscion regalis

INTRODUCTION

We aged 366 weakfish, *Cynoscion regalis*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2008. The weakfish ages ranged from 1 to 14 years old with an average age of 2.7, and standard deviation of 1.4, and a standard error of 0.07. Nine age classes (1 to 6, 9, 12, and 14) were represented, comprising fish from the 1994, 1996, 1999, and 2002 through 2007 year-classes. Fish from the 2005 year-class dominated the sample with 37%, followed by 2006 (27%).

METHODS

Sample size for ageing — We estimated sample size for ageing weakfish in 2008 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing weakfish in 2008; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of weakfish collected from 2002 to 2007 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of weakfish used by VMRC to estimate length distribution of the catches from 2002 to 2007. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) that will be obtained. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored dry inside of protective Axygen 2.0 ml microtubes within their original labeled coin envelopes.

Preparation — Sagittal otoliths (hereafter, referred to as "otoliths") were processed for age determination following our thin-sectioning method, as described in Chapter 1, 2, 5, and 8 for other sciaenids. The left or right sagittal otolith was randomly selected and attached to a glass slide with clear Crystalbond™ 509 adhesive. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section) was then removed from marked core of each otolith using a Buehler® IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton® diamond grinding wheels (hereafter, referred to as "blades), separated by a stainless steel spacer of 0.4 mm (diameter 2.5"). The position of the marked core fell within the 0.3mm space between the blades, such that the core was included in the transverse cross-section removed. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x + x", where "x" is the number of annuli in the thin-section.

If the fish is captured between January 1 and the end of the species specific annulus deposition period, it is assigned an age class notation of "x + (x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, weakfish otolith deposition occurs between April and May (Lowerre-Barbieri et al. 1994). A weakfish captured between January 1 and May 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x + (x+1)" or 3 + (3+1), noted as 3 + 4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus formation, which would be noted as 4 + 4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

Figure 1. Sectioned otolith of a female weakfish with 6 annuli.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses and figures were made using R (R Development Core Team 2009).

RESULTS

We estimated a sample size of 366 for ageing weakfish in 2008, ranging in length interval from 6 to 36 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 2 and the largest CV of 17% for age 5 fish. In 2008, we randomly selected and aged 366 fish from 671 weakfish collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 47 fish. However, these were primarily from the very large length intervals (Table 1), therefore, the precision for the estimates of major age groups (such as age 2 and 3) would not be influenced significantly.

The measurement of reader self-precision was high for both readers. Reader 1 had an agreement of 96% with a CV of 1% ' (test of symmetry: $\chi^2 = 2$, df = 2, $P = 0.3679$). Reader 2 had a 100% agreement. There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 98.6% and a CV of smaller than 0.4% (Figure 2).

There is no time-series bias for both readers. Reader 1 had an agreement of 100% with ages of fish aged in 2000. Reader 2 had an agreement of 98% with ages of fish aged in 2000 with a CV of 1% (test of symmetry: $\chi^2 = 1$, df = 1, P = 0.3173).

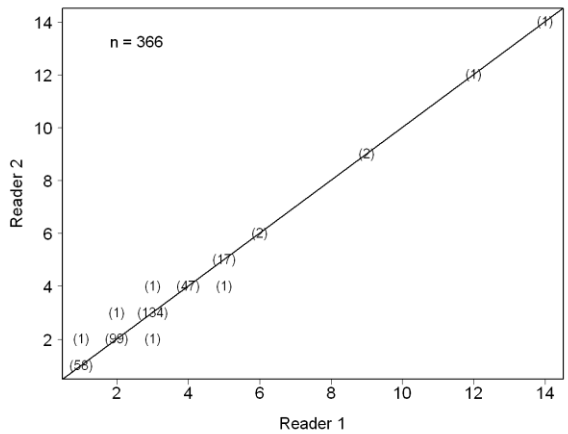


Figure 2. Between-reader comparison of otolith age estimates for weakfish collected in Chespakead Bay and Virginia waters of the Atlantic in 2008.

Of the 366 fish aged with otoliths, 9 age classes were represented (Table 2). The average age was 2.7 years old, and the standard deviation and standard error were 1.4 and 0.07, respectively.

Year-class data shows that the fishery was comprised of 9 year-classes, comprising fish from the 1994, 1996, 1999, 2002 through 2007 year-classes, with fish primarily from the 2005 year-classes (37%). The females (75%) were highly dominant in the sample collected in 2008 (Figure 3).

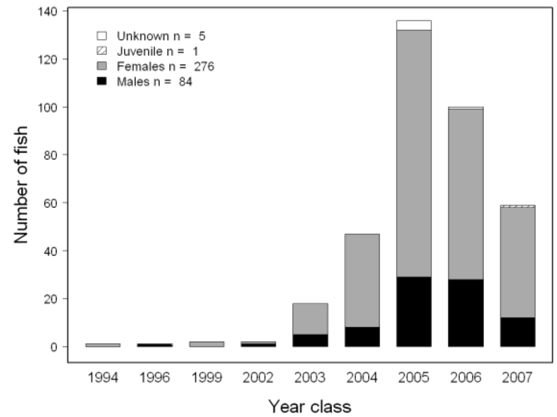


Figure 3. Year-class frequency distribution for weakfish collected for ageing in 2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

Lowerre-Barbieri, S.K., M.E. Chittenden Jr., and C.M. Jones. 1994. A comparison of a validated otolith method to age weakfish, *Cynoscion regalis*, with the traditional scale method. Fish Bull. 92:555-568.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Table 1. Number of weakfish collected and aged in each 1-inch length interval in 2008. "Target" represent the sample size for ageing estimated for 2008, "Collected" represents number of fish with both total length and otoliths, and "Need" represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
6 - 6.99	5	0	0	5
7 - 7.99	5	4	4	1
8 - 8.99	5	23	8	0
9 - 9.99	25	49	28	0
10 - 10.99	56	74	56	0
11 - 11.99	42	52	42	0
12 - 12.99	31	63	31	0
13 - 13.99	22	85	22	0
14 - 14.99	18	83	21	0
15 - 15.99	17	56	19	0
16 - 16.99	14	45	15	0
17 - 17.99	11	27	12	0
18 - 18.99	11	22	20	0
19 - 19.99	9	14	14	0
20 - 20.99	9	20	20	0
21 - 21.99	8	11	11	0
22 - 22.99	7	10	10	0
23 - 23.99	6	6	6	0
24 - 24.99	5	6	6	0
25 - 25.99	5	3	3	2
26 - 26.99	5	3	3	2
27 - 27.99	5	0	0	5
28 - 28.99	5	1	1	4
29 - 29.99	5	7	7	0
30 - 30.99	5	1	1	4
31 - 31.99	5	1	1	4
32 - 32.99	5	1	1	4
33 - 33.99	5	3	3	2
34 - 34.99	5	0	0	5
35 - 35.99	5	1	1	4
36 - 36.99	5	0	0	5
Totals	366	671	366	47

Table 2. The number of weakfish assigned to each total length-at-age category for 366 fish sampled for otolith age determination in Virginia during 2008.

	Age									
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**9**	**12**	**14**	**Totals**
7 - 7.99	3	1	0	0	0	0	0	0	0	4
8 - 8.99	6	0	2	0	0	0	0	0	0	8
9 - 9.99	11	16	1	0	0	0	0	0	0	28
10 - 10.99	19	27	10	0	0	0	0	0	0	56
11 - 11.99	13	19	7	3	0	0	0	0	0	42
12 - 12.99	7	13	10	1	0	0	0	0	0	31
13 - 13.99	0	5	15	2	0	0	0	0	0	22
14 - 14.99	0	5	13	3	0	0	0	0	0	21
15 - 15.99	0	2	9	6	2	0	0	0	0	19
16 - 16.99	0	2	11	2	0	0	0	0	0	15
17 - 17.99	0	2	5	5	0	0	0	0	0	12
18 - 18.99	0	2	14	4	0	0	0	0	0	20
19 - 19.99	0	3	4	6	1	0	0	0	0	14
20 - 20.99	0	2	15	2	1	0	0	0	0	20
21 - 21.99	0	0	7	2	1	1	0	0	0	11
22 - 22.99	0	0	2	2	6	0	0	0	0	10
23 - 23.99	0	1	2	2	1	0	0	0	0	6
24 - 24.99	0	0	3	2	1	0	0	0	0	6
25 - 25.99	0	0	2	1	0	0	0	0	0	3
26 - 26.99	0	0	1	1	0	1	0	0	0	3
28 - 28.99	0	0	1	0	0	0	0	0	0	1
29 - 29.99	0	0	2	2	3	0	0	0	0	7
30 - 30.99	0	0	0	0	1	0	0	0	0	1
31 - 31.99	0	0	0	1	0	0	0	0	0	1
32 - 32.99	0	0	0	0	0	0	0	0	1	1
33 - 33.99	0	0	0	0	1	0	1	1	0	3
35 - 35.99	0	0	0	0	0	0	1	0	0	1
Totals	59	100	136	47	18	2	2	1	1	366

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for weakfish sampled for age determination in Virginia during 2008.

	Age								
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**9**	**12**	**14**
7 - 7.99	0.75	0.25	0	0	0	0	0	0	0
8 - 8.99	0.75	0	0.25	0	0	0	0	0	0
9 - 9.99	0.393	0.571	0.036	0	0	0	0	0	0
10 - 10.99	0.339	0.482	0.179	0	0	0	0	0	0
11 - 11.99	0.31	0.452	0.167	0.071	0	0	0	0	0
12 - 12.99	0.226	0.419	0.323	0.032	0	0	0	0	0
13 - 13.99	0	0.227	0.682	0.091	0	0	0	0	0
14 - 14.99	0	0.238	0.619	0.143	0	0	0	0	0
15 - 15.99	0	0.105	0.474	0.316	0.105	0	0	0	0
16 - 16.99	0	0.133	0.733	0.133	0	0	0	0	0
17 - 17.99	0	0.167	0.417	0.417	0	0	0	0	0
18 - 18.99	0	0.1	0.7	0.2	0	0	0	0	0
19 - 19.99	0	0.214	0.286	0.429	0.071	0	0	0	0
20 - 20.99	0	0.1	0.75	0.1	0.05	0	0	0	0
21 - 21.99	0	0	0.636	0.182	0.091	0.091	0	0	0
22 - 22.99	0	0	0.2	0.2	0.6	0	0	0	0
23 - 23.99	0	0.167	0.333	0.333	0.167	0	0	0	0
24 - 24.99	0	0	0.5	0.333	0.167	0	0	0	0
25 - 25.99	0	0	0.667	0.333	0	0	0	0	0
26 - 26.99	0	0	0.333	0.333	0	0.333	0	0	0
28 - 28.99	0	0	1	0	0	0	0	0	0
29 - 29.99	0	0	0.286	0.286	0.429	0	0	0	0
30 - 30.99	0	0	0	0	1	0	0	0	0
31 - 31.99	0	0	0	1	0	0	0	0	0
32 - 32.99	0	0	0	0	0	0	0	0	1
33 - 33.99	0	0	0	0	0.333	0	0.333	0.333	0
35 - 35.99	0	0	0	0	0	0	1	0	0

Chapter 14

Sheepshead

Archosargus probatocephalus

INTRODUCTION

During 2008, a total of 167 sheepshead, *Archosargus probatocephalus*, were collected and aged, giving us a total of 559 fish collected between 2006 and 2008, of which 557 were aged. The two individuals were not aged due to the loss of the sagittal otoliths. Ages of collected sheepshead ranged from 0 (young-of-the-year; YOY) to 35 years old with an average age of 6.5, a standard deviation of 7.06, and a standard error of 0.3 years. Further, sheepshead representing 33 age classes (0 to 26, 29, 30, and 32 to 35), comprising 29 year classes (1973, 1974, 1977, and 1983-2007) were observed. In the total sample, the 2007 year-class was dominant (39%), followed by the year classes of 1997 (10%) and 2001(10%). With regards to growth, the sheepshead of Chesapeake Bay grew very rapidly up to 5 years-of-age, but by age 10, growth had begun to slow. Further, in general, their growth was faster and they obtained larger maximum sizes than sheepshead from South Carolina, Florida, and Louisiana. Macroscopic gonad inspection and histological staining suggests that sheepshead in Chesapeake Bay are multiple batch spawners from December to June, and that 100% of females mature at age 5 (about 18 in.).

The presence of YOY, faster growth rates, and local spawning activity suggest the sheepshead of Chesapeake Bay are indeed a local population that are governed by their unique vital rates and population dynamics. First, we suggest that a minimum length limit of 19 in. should be established so that the spawning stock of sheepshead in Chesapeake Bay could be protected. Then, we evaluated potential management options to benefit both commercial and recreational fisheries using a yield per recruit model. We found that the slot limit of 19-20 in. could provide an optimal yield (64-73% of cohort lifetime maximum yield per recruit) and maximize trophy fish catch under both the low and high end of natural mortality.

METHODS

1. Field work

1) Recreational sampling
In 2008, we continued to work with recreational anglers closely. As in 2007, coolers were distributed to the same four

marinas and brochures were distributed to promote the project. The Marina at Marina Shores and Long Bay Pointe Marina both allowed the coolers to remain on site and volunteered to check coolers daily for the presence of sheepshead. The two remaining marinas, Taylor's Landing and Little Creek Marina, had coolers on site on weekends and major holidays. Further, to increase the sample size, we hired a charter boat for five days to collect sheepshead during the summer of 2008. In addition, Center for Quantitative Fisheries Ecology (CQFE) staff undertook several trips with local recreational hook-and-line anglers and spearfishers to collect sheepshead.

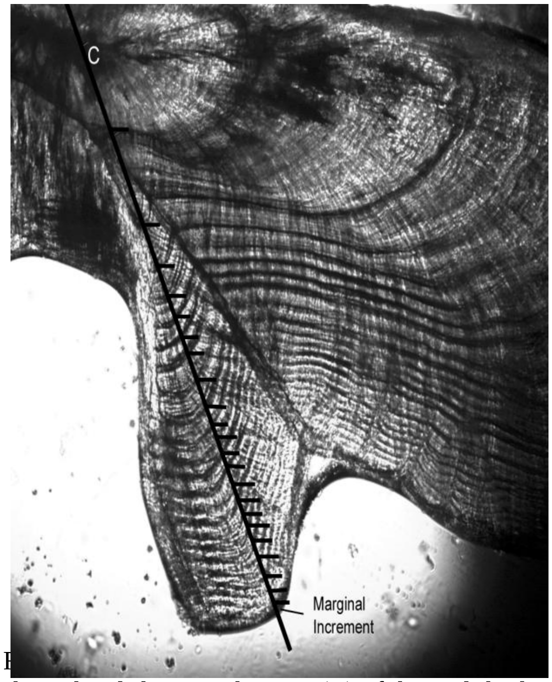
2) Commercial sampling
In 2008, we collected sheepshead from commercial fisheries with the help of the Virginia Marine Resources Commission (VMRC). VMRC employees sampled the commercial sectors daily and collected all the sheepshead they intercepted for us.

3) Independent sampling
Because most of the sheepshead we collected from the recreational and commercial fisheries were larger than 21 in. and greater than 4 years old in 2006 and 2007, we continued to try and collect small juvenile sheepshead from mid to lower bay seagrass beds in 2008. We collaborated with the Virginia Institute of Marine Sciences (VIMS) and other members of the CQFE to collect any sheepshead encountered while trawling for spotted seatrout (*Cynoscion nebulosus*) on seagrass beds during the summer and fall.

2. Lab work

Once collected, we brought the sheepshead back to the CQFE where they were immediately processed in the lab. Weights and lengths (total length (TL), fork length (FL), and standard length (SL)) were recorded to the nearest 0.001 pounds (lbs; 0.5 grams) and 1 millimeter (mm; 0.04 inches), respectively. In addition, we removed their sagittal otoliths for aging and female gonads for microscopic gonadal stage. Finally, we removed scales and pelvic spines, took muscle tissue samples, and preserved their stomachs for use in other studies on sheepshead of the Chesapeake Bay.

To age each individual, we mounted an otolith from each fish to a microscope slide. Subsequently, the otolith was sectioned using a Buehler Isomet saw equipped with two Norton diamond wafering blades separated by a 0.4 mm stainless steel spacer, positioned so that the wafering blades straddled the core of the otolith. This produces an otolith transverse section that is used for aging. We then placed each section on a labeled glass slide and covered it with a thin layer of Flo-texx mounting medium (Figure 1).



F
sheepshead showing the core (C) of the otolith, the measuring axis with annuli marked, and the marginal increment or growth on the edge of the otolith.

Before preserving the gonads in formalin, staff macroscopically evaluated the maturity

For fish for which upon macroscopic examination of the gonads a sex could not be determined, they were considered immature, and given a maturity stage of 0.

Subsequently, we used the macroscopic maturity stages to determine the lengths and ages at maturity for both male and female sheepshead using a logistic equation. This information was critical in determining the lengths and ages at 50% maturity and 100% maturity that is useful in developing management strategies for fish species. When developing the logistic curves, for both males and females, any fish which could be identified as either a male or female was assumed to be mature.

After we had macroscopically staged the gonads of females, we removed and weighed the gonads to the nearest 0.1 g and preserved them in 10% buffered formalin for further histological analysis. The Department of Pathobiological Sciences at Louisiana State University (LSU) helped us to make histology slides for histological analysis (microscopic analysis). Before we sent the ovaries to LSU, they were prepared as follows:

i) Selected a portion of the ovaries (usually the middle portion) and sliced a cube about 1 x 1 x 1 cm.
ii) Rinsed the sample with tap water 3 times, for 30 minutes each.
iii) Transferred the sample from the final tap water rinse to 70% Ethanol in a 20-ml scintillation vial and sealed it with the cap.

The histological analysis was used to determine the microscopic gonadal stage of female ovaries, which we used to determine the spawning strategy (batch vs. total spawner) and to identify the potential spawning season of Chesapeake Bay sheepshead. We followed the microscopic staging system developed by Brown-Peterson et al. (2007), which is a 6 stage system with the following categories:

1) Immature
2) Developing
3) Spawning Capable
4) Spawning
5) Regressing
6) Regenerating.

Each stage is identified by the presence of certain structures (e.g.: post ovulatory follicles, α-Atresia, β-atresia, ovarian wall thickness, muscle bundles) and types of oocytes (e.g.: primary growth oocytes, cortical alveoli, vitellogenic oocytes, and hydrated oocytes) in the ovary. Fish identified as having gonads in the spawning capable or spawning category are considered to be actively spawning, and thus their presence can be used to identify the spawning season.

3. Age determination

Using polarized light and an image analysis system, we aged the otoliths, without prior knowledge of fish length or date of capture, by counting individual annuli. To confirm the formation of one annulus per year, we used marginal increment analysis. Further, a symmetric test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers for three years pooled (2006 - 2008), 2) within the primary reader for three years pooled (2006 – 2008), and 3) time-series bias between 2006 and 2008 within each reader. The readings from the entire sample for the current year were used to examine the difference between the two readers. The primary reader aged all the fish collected from 2006 through 2008 twice to examine read-self precision. Fifty otoliths randomly selected from fish aged in 2006 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistical analyses and figures were made using R (R Development Core Team 2009).

Due to the small sample sizes from individual years, we developed an age-length-key (ALK) using otolith ages pooled from 2006 to 2008.

4. Growth model development

To develop von-Bertalanffy growth models for sheepshead in Chesapeake Bay, we first developed von-Bertalanffy growth models for each sex for each year. Subsequently, using Kimura's likelihood ratio test (Kimura 1980), we compared the resulting sex specific growth curves within each year. When no significant differences were found between the two sex models, a year-specific growth model was developed using sex-pooled data within each year. The year-specific models among three years were then compared using Kimura's likelihood ratio test. When no significant differences were found among the year-specific models, the male and female models were developed using year-pooled data separately. Finally, Kimura's likelihood ratio test was used to test for differences between the sex-specific year-pooled growth models. If there was no significant difference, then, a sex- and year-pooled model was developed. If there was a significant difference, then, sex-specific year-pooled models were kept.

5. Mortality estimates

Total mortality (Z) – Total mortality estimates were obtained by performing a catch-curve analysis (Quinn and Deriso

1999) on the CQFE sheepshead catch-at-age data. In the analysis, linear regression is used to fit the following relationship,

$$\ln(N_t) = a + bt\ , \qquad (1)$$

where t is age, N_t is the catch at age t, and a and b are the two parameters estimated via regression. The absolute value of the slope parameter, b, provides an estimate of the instantaneous total mortality rate (Z). In practice, if there are missing age groups in the catch-curve analysis, a value of 1 is added to all numbers-at-age used in the analysis prior to natural log transformation.

Natural mortality (M) – Two different natural mortality rate estimators were used in our study. The first is based on a linear regression model (Hoenig 1984). Hoenig (1984) recommends using the predictive equation:

$$\ln(\widehat{M}) = 1.44 - 0.982 \ln(t_{max}), \qquad (2)$$

where $\widehat{M}$ is an estimate of the instantaneous natural mortality rate (M), and t_{max} is the maximum age observed.

The second method is based on a pre-determined percentage of individuals in the stock surviving to the age t_{max} (Quinn and Deriso 1999):

$$\widehat{M} = \frac{-\ln(p)}{t_{max}}, \qquad (3)$$

where p is the percentage of individuals achieving t_{max}. It is common practice to develop a range of plausible natural mortality rates by allowing p to be either 1% or 5% (Quinn and Deriso 1999).

These two methods have been used extensively in work related to stock assessments for blue crab (*Callinectes sapidus*) (Hewitt and Hoenig 2005).

6. Yield-per-recruit model (YPR)

A Beverton-Holt YPR model was used to estimate the yield per recruit of Chesapeake Bay sheepshead under various combinations of exploitation rates (E) and minimum length limits (L_c) (Quinn and Deriso 1999).

Because we estimated β between 2.99 and 3.05, we assumed that sheepshead in Chesapeake Bay had an isometric relationship between length and weight, β = 3. Then, we estimated the critical age (t*) at which the cohort biomass of sheepshead in Chesapeake Bay reaches its peak as follows:

$$t^* = t_0 + \frac{1}{k}\ln\left(1 + \frac{\beta}{m}\right), \qquad (4)$$

where $m = M/k$, and k and t_0 are parameters from a sex- and year-pooled von Bertalanffy growth model in terms of fish fork length. Before we estimated the cohort lifetime maximum yield per recruit (Y^*/R) at t^*, we estimated the following parameters:

$$B^* = W^* N^*, \qquad (5)$$

$$W^* = W_\infty\left[1 - e^{-k(t^* - t_0)}\right]^\beta, \qquad (6)$$

$$N^* = N_r e^{-M(t^* - t_r)}, \qquad (7)$$

where B^*, W^*, and N^* are the cohort biomass, average weight, and number of fish at critical age t^*, respectively. k and t_0 are defined as previously. t_r is defined as the first possible age of exploitation, therefore, N_r is the number of fish (recruitment) at t_r. W_∞ is the average maximum weight and can be estimated as follows (Quinn and Deriso 1999):

$$W_\infty = \alpha L_\infty^\beta \qquad (8)$$

where β = 3, and L_∞ is the average maximum length. α can be estimated using the relationship between length (L) and weight (W):

$$\ln W_i - \beta \ln L_i = \ln \alpha + \epsilon_i, \qquad (9)$$

for i = 1, …, n for the total number of fish collected, and β = 3. The estimate of lnα using linear least squares is just the mean of the left-hand side of Equation 9 (Quinn and Deriso 1999):

$$\widehat{\ln \alpha} = \overline{\ln W} - 3\,\overline{\ln L}$$

For easy calculation in the YPR modeling, N_r is set to 1000 fish. We set t_r as age 1 for sheepshead in Chesapeake Bay. Then, we estimated

$$Y^*/R = B^*/N_r, \qquad (10)$$

Y^*/R will be used as one of the references to make fisheries management decisions.

To estimate the length (L^*) at the critical age t^*, we used the von Bertalanffy equation:

$$L^* = L_\infty\left[1 - e^{-k(t^* - t_0)}\right], \qquad (11)$$

where L_∞, k and t_0 are defined as previously. Then, the lifetime yield (%) from a cohort at L^* was calculated as follows:

$$y^* = E \sum_{n=0}^{3} \frac{U_n(1-c^*)^{n+m}}{1+n(1-E)/m} \qquad (12)$$

where E is exploitation rate ($E = F/Z$), $c^* = L^*/L_\infty$. For the cubic expression (β = 3), U_n = +1, -3, +3, -1 for n = 0, 1, 2, 3, respectively.

We defined t_c as the age when all the fish in the cohort reaches the minimum length limit (L_c) for sheepshead fisheries. L_c can be calculated using Equation 11 by replacing L^* and t^* with L_c and t_c, respectively.

Therefore, at a given L_c and exploitation rate (E), we estimated lifetime yield (y_c) from a cohort using Equation 12 by replacing y^* and c^* with y_c and c_c, respectively.

Then, yield per recruit at given L_c and E was estimated as follows:

$$Y_c/R = (Y^*/R)\,\frac{y_c}{y^*} \qquad (13)$$

7. Fisheries management implication

Target and threshold fishing mortality – Using the yield per recruit model, we can find a maximum yield per recruit with an exploitation rate at the maximum yield per recruit (E_{max}) using a trial and error method. Then, a corresponding fishing mortality rate at the maximum yield per recruit (F_{max}) was estimated using the equation

$$F_{max} = \frac{ME_{max}}{1 - E_{max}}, \qquad (14)$$

However, F_{max} can frequently exceed sustainable harvest rates and is not considered a conservative policy (Quinn and Deriso 1999). Therefore, an alternative fishing mortality rate, called $F_{0.1}$, is adapted for a more conservative fisheries management policy. $F_{0.1}$ can be estimated using Equation 14 by replacing F_{max} and E_{max} with $F_{0.1}$ and $E_{0,1}$, respectively:

$E_{0.1}$ can be obtained using a trial and error method to make the left and right sides are equal in the following equation:

$$\sum_{n=0}^{3} \frac{U_n(1-c_c)^n}{\left[1+\frac{n(1-E_{0.1})}{m}\right]^2}\left(1+\frac{n}{m}\right) = \frac{0.1}{(1-E_{0.1})^2}\sum_{n=0}^{3}\frac{U_n(1-c_c)^n}{(1+\frac{n}{m})} \quad . \qquad (15)$$

where U_n and n are defined as previously.

When developing management recommendations for Chesapeake Bay sheepshead, we defined the stock as undergoing overfishing if the fishing mortality rate (F) exceeds $F_{0.1}$. This overfishing threshold is consistent with the general structure of the North Pacific Groundfish Fishery Management Plan tier structure (Goodman et al. 2002) and the applicability of $F_{0.1}$ as a proxy for F_{max} when data is insufficient to obtain biomass estimates or construct a surplus production model. In addition, this conservative reference point is warranted given the uncertainty in stock structure and the spawning biomass required to maintain average recruitment levels. The threshold value of $F_{0.1}$ should be viewed as an overfishing limit (F_{OFL}), thus, using a precautionary approach, the probability of exceeding this $F_{0.1}$ should be sufficiently small (< 5% of the time) so as to maintain the current stock structure (Goodman et al. 2002).

Further, we define the acceptable biological catch (F_{ABC}) as a rate of fishing mortality equaling 75% of the fishing mortality rate at $F_{0.1}$ (0.75*$F_{0.1}$). Once again, this overfishing level is consistent with the precautionary approach mandated by the Magnuson-Stevens Fisheries Conservation and Management Act for the management of species found in federal waters and with the North Pacific Groundfish Fishery Management Plan tier structure (Goodman et al. 2002). The buffer between the F_{OFL} and F_{ABC} is warranted given the degree of uncertainty regarding sheepshead stock parameters and data deficiencies.

Because there are no current biomass estimates for sheepshead in Chesapeake Bay, it is impossible to construct analogous biomass reference points indicating when the population is overfished.

Subsequently, once the F_{ABC} had been calculated, to estimate the exploitation rate at the allowable biological catch (E_{ABC}) we utilized equation 14, but replacing F_{max} and E_{max} with F_{ABC} and E_{ABC}, respectively and solving for E_{ABC}. Finally, the yield per recruit under F_{ABC} can be estimated using Equation 12 and 13 by replacing E with E_{ABC}.

Trophy fishery - Our study over the previous three years has indicated that Chesapeake Bay sheepshead is a unique stock with its own vital rates. They are much longer and heavier at age than their counterparts in the South Atlantic and Gulf of Mexico. Therefore, we estimated the fishing mortality rate (F_{trmax}) needed to maximize the harvest of trophy fish, which we defined as a fish equal to or larger than A fork length 22 in., which corresponds to an average age of 17 (t_{tr}). To do this, we modeled two scenarios, a minimum length limit and a slot limit.

For the minimum length limit (L_c) at t_c,

$$F_{trmax} = \frac{-M(t_{tr}-t_c)+\sqrt{M^2(t_{tr}-t_c)^2+4M(t_{tr}-t_c)}}{2(t_{tr}-t_c)} \quad (16)$$

Therefore, the maximum catch of trophy fish (C_{tr}) is

$$C_{tr} = \frac{F_{trmax}}{F_{trmax}+M} N_r e^{-M(t_c-t_r)-(F_{trmax}+M)(t_{tr}-t_c)} \quad (17)$$

The corresponding non-trophy fish catch (C_{nt}) is

$$C_{nt} = \frac{F}{F+M} N_r e^{-M(t_c-t_r)}\left[1-e^{-(F+M)(t-t_c)}\right], \quad (18)$$

where $t = t_{tr}$ -1.

For the slot limit, we defined $t_c < t_f < t_{tr}$. Fish allowed to be kept are between age t_c and t_f, and equal to or larger than length t_{tr}. Here

$$F_{trmax} = \frac{-M(t_f-t_c)+\sqrt{M^2(t_f-t_c)^2+4M(t_f-t_c)}}{2(t_f-t_c)}, \quad (19)$$

Then, the maximum catch of trophy fish is

$$C_{tr} = \frac{F_{trmax}}{F_{trmax}+M} N_r e^{-M(t_c-t_r)-(F_{trmax}+M)(t_f-t_c)-M(t_{tr}-t_f)} \quad (20)$$

The corresponding non-trophy fish catch is

$$C_{nt} = \frac{F}{F+M} N_r e^{-M(t_c-t_r)}\left[1-e^{-(F+M)(t_f-t_c)}\right] \quad (21)$$

Management options for both commercial and recreational fisheries – Because we didn't have estimates of spawning stock biomass for sheepshead in Chesapeake Bay, we made a conservative criterion for setting up the minimum length limit to protect the spawning stock. The minimum length limit must be larger than the fork length at which 100% of fish in the cohort are mature and are able to spawn.

Fishing mortality was set up in terms of three criteria:

1) Below or equal to the fishing mortality F_{ABC}.
2) Not causing a significant reduction from the cohort lifetime maximum yield per recruit.
3) Maximizing trophy fish catch.

RESULTS

1. Sample collection

During 2008, we collected 167 sheepshead, making a total of 559 fish collected, and 557 fish aged during the three years of the study. Of the 559 sheepshead collected, 266 (48%) fish were obtained from recreational anglers, 231 (41%) fish from commercial fisheries, and 62 (11%) from fishery independent sampling. Among those fish, 144 (25.8%) were male, 219 (39.2%) were female, 191 (34.2%) were YOY, and 5 (0.9%) were of unknown sex. This corresponds to a female to male sex ratio of 1.52:1. Total lengths of sheepshead collected ranged from a minimum of 0.98 in. to a maximum of 26.7 in. while fish weights ranged from a minimum of 0.0007 lbs. to a maximum of 19.9 lbs.

2. Age determination

There was no significant difference between the first and second readings for the primary reader (test of symmetry: $\chi^2 = 34.44$, df = 28, $P = 0.1866$), and between the primary and secondary readers (test of symmetry: $\chi^2 = 36.05$, df = 32, $P = 0.2847$). The average CVs were 1.1% and 2.2% for the primary reader and between the two readers, respectively. Agreement between the first and second readings for the primary reader was 89% (Figure 2), and between the primary and secondary readers was 77% (Figure 3).

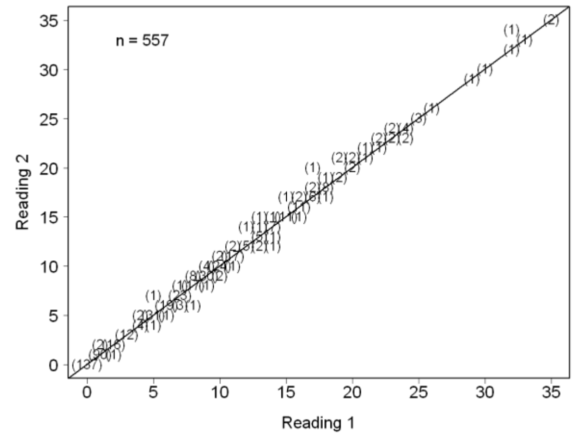


Figure 2. The primary reader's between-reading comparison of otolith age estimates for sheepshead collected in 2006-2008.

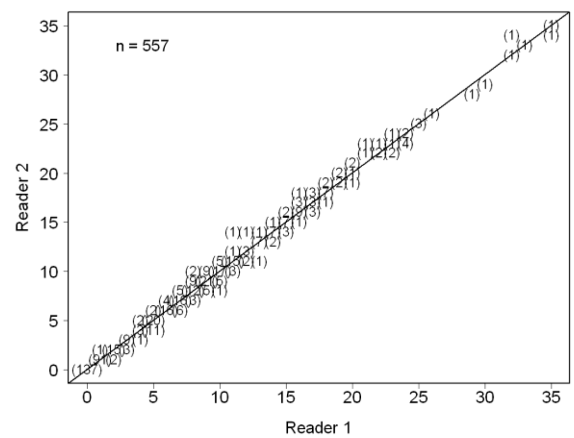


Figure 3. Between-reader comparison of otolith age estimates for sheepshead collected in 2006-2008.

There is no time-series bias for both readers. The primary reader (Reader 1) had an agreement of 74% with the ages of fish aged in 2006 with a CV of 2% (test of symmetry: $\chi^2 = 11$, df = 11, $P = 0.4433$). The secondary reader (Reader 2) had an agreement of 52% with ages of fish aged in 2006 with a CV of 3.5% (test of symmetry: $\chi^2 = 15.2$, df = 17, $P = 0.5811$).

We aged all 167 fish collected in 2008, making up a total of 557 sheepshead aged during the three years of the study. Two sheepshead (one male and one female) collected in previous years were not aged due to the loss of the sagittal otoliths. The ages of the 557 sheepshead ranged from a minimum of 0 years old (YOY) to a maximum of 35 years old with an average of 6.5 years, a standard deviation of 7.06 years, and a standard error of 0.3 years. Thirty-three age classes (0 to 26, 29, 30, and 32 to 35) were represented (Table 1), comprising 29 year classes (1973, 1974, 1977, and 1983-2007). Sheepshead from the 2007 year-class were dominant (39%), followed by individuals from the year classes of 1997 (10%) and 2001 (10%) in the three-year sample (Figure 4).

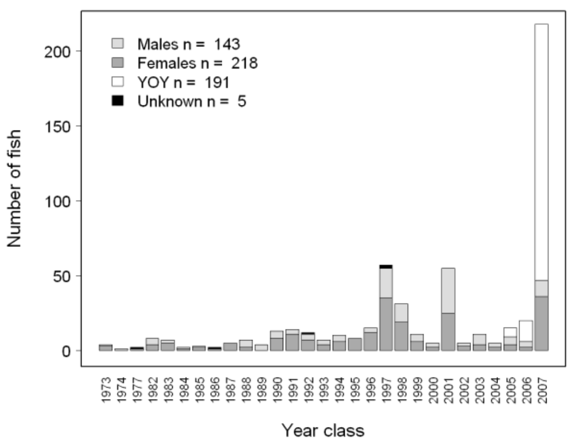


Figure 4. Year-class frequency distribution for sheepshead collected in 2006-2008. Distribution is broken down by sex. “Unknown” is used for specimen that were not eligible for gonad extraction, or, during sampling, the sex was not examined.

Age-Length-Key — We present an age-length-key (Table 2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC’s stratified sampling of landings by total length inch intervals.

3. Growth

Kimura’s likelihood ratio test indicated that there were no dimorphic differences in growth rates between male and female sheepshead within each year (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.3461$ for 2006, $P = 0.2464$ for 2007, $P = 0.2175$ for 2008) and between years with the sex-pooled within each year (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.8786$ for 2006 vs. 2007, $P = 0.6422$ for 2007 vs. 2008, $P = 0.9751$ for 2006 vs. 2008). However, there was a significant difference between the male and female year-pooled growth models (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.032$). Therefore, a year-pooled von Bertalanffy growth model was developed for each sex (Figure 5). In general, sheepshead in Chesapeake Bay grew very rapidly before 5 years-of-age, but by age 10, growth began to slow. Females grew faster and were larger at age than males.

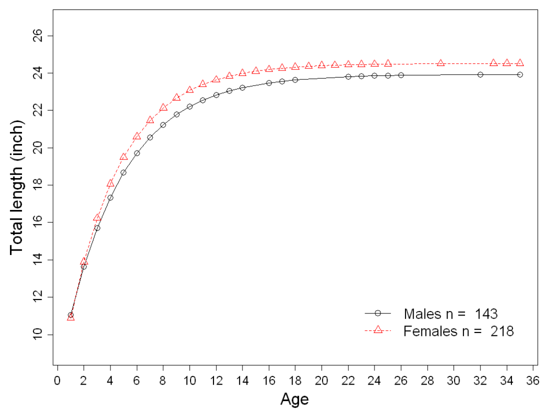


Figure 5. von Bertalanffy growths by male and female sheepshead collected in 2006-2008.

The von Bertalanffy length growth models for males and females are

$TL = 23.92\left[1 - e^{-0.224(t-(-1.766))}\right]$ and

$TL = 24.52\left[1 - e^{-0.249(t-(-1.357))}\right]$,

respectively,

where *TL* is total length in inches and *t* is age in years.

We compared the growth of sheepshead in Chesapeake Bay to those in other areas using the year-pooled and sex-specific growth model of Chesapeake sheepshead. Anecdotally, we suspected sheepshead of Chesapeake Bay were larger at age than sheepshead from other areas and were generally attaining larger maximum fork lengths and weights (Table 3). Using Kimura's (1980) likelihood ratio test, Helser's (1996) randomization test, and the variance ratio test (Zar 1996), we confirmed this, as there are significant differences (p<0.001 for all tests) in growth rates between Chesapeake Bay sheepshead and sheepshead from South Carolina (McDonough, pers. comm.), Florida (Dutka-Gianelli and Murie 2001; MacDonald, pers. comm.; MacDonald et al. In Review; Munyandorero et al. 2006), and Louisiana (Beckman et al. 1991) in terms of their length and weight. The models for Chesapeake Bay suggests that sheepshead of the region are exhibiting fast growth until age 8 and 10 for length (Figure 6) and weight (Figure 7), respectively, after which growth begins to slow. In other areas, it appears that growth in length and weight begins to slow much earlier during the lifespan, with growth rates beginning to slow between age 4 and 8. Thus, by age 10, though sheepshead in Chesapeake Bay average approximately 525 mm (21 in) FL and 4 kg (9 lbs), in other areas they are only between 350 (14 in) and 450 mm (18 in) in fork length and weigh 2 kg (4 lbs).

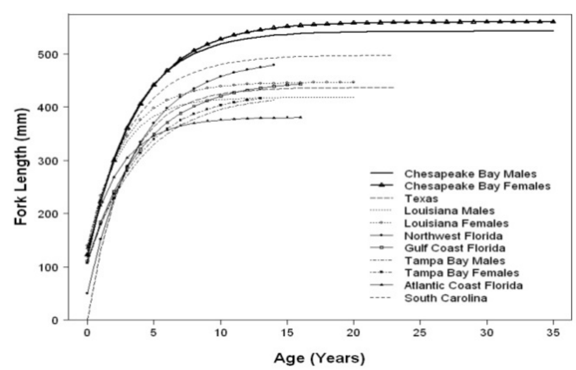


Figure 6. von Bertalanffy length growth curve for Chesapeake Bay and those published for sheepshead from other areas.

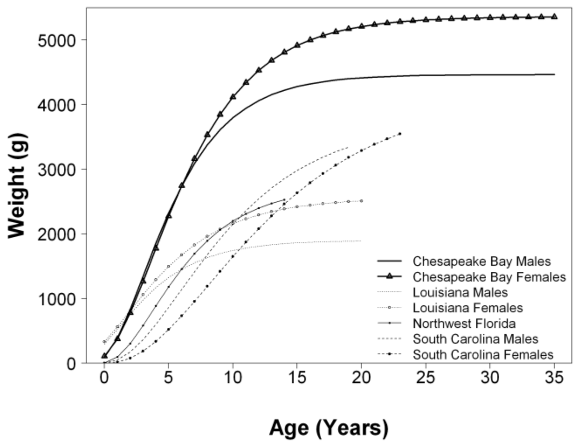


Figure 7. von Bertalanffy weight growth curve for Chesapeake Bay and those published from other areas.

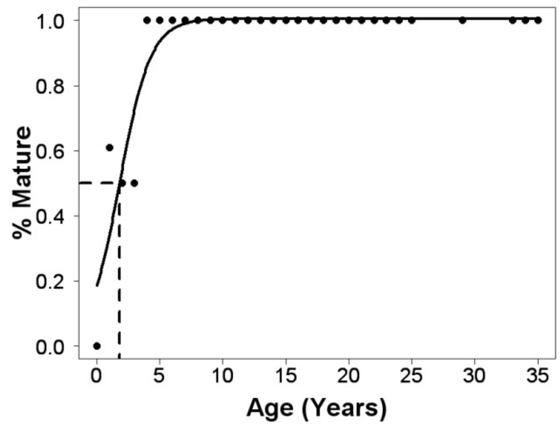


Figure 8. Age at maturity ogive for Chesapeake Bay female sheepshead collected between 2006 and 2008. Dashed line indicates the age at 50% maturity.

4. Maturity and spawning season

From our collections in 2006-2008, we were able to conduct macroscopic examinations on 345 sheepshead for which we knew the date of capture. Of these, 204 were female and 141 were male.

For females, logistic regression suggests that the age at 50% maturity is 1.01 years (Figure 8) and the length at 50% maturity is 252 mm FL (Figure 9). All females are mature by age 4 and at 350 mm FL. For males, the maturity curves (Figure 10 and Figure 11) indicate similar but slightly later ages and lengths at 50% maturity, those being 1.47 years and 278 mm FL, respectively. All males were mature by age 4 and by 325 mm FL.

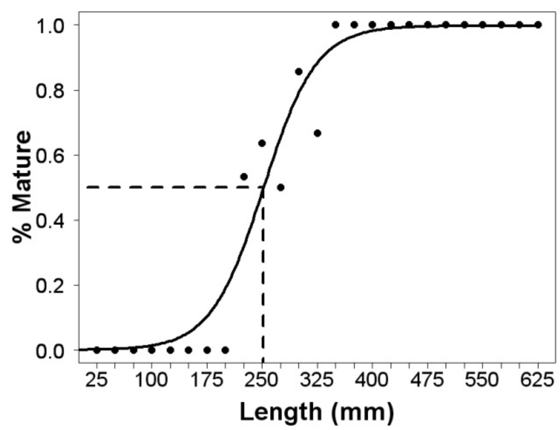


Figure 9. Length at maturity ogive for Chesapeake Bay female sheepshead collected between 2006 and 2008. Dashed line indicates the length at 50% maturity.

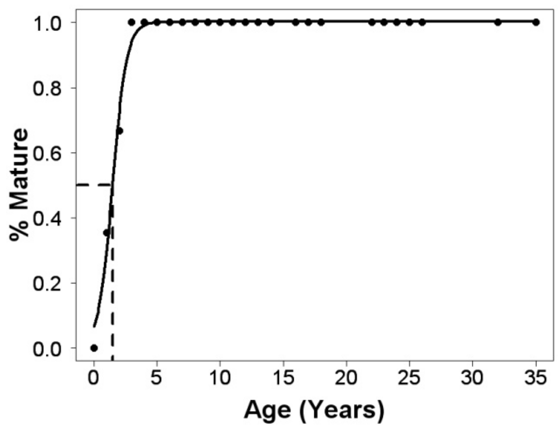


Figure 10. Age at maturity ogive for Chesapeake Bay male sheepshead collected between 2006 and 2008. Dashed line indicates the age at 50% maturity.

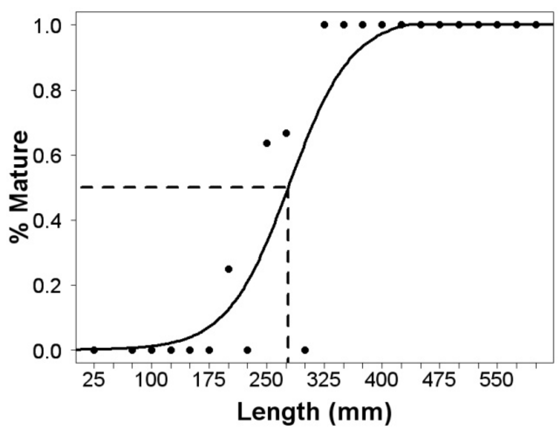


Figure 11. Length at maturity ogive for Chesapeake Bay male sheepshead collected between 2006 and 2008. Dashed line indicates the length at 50% maturity.

Histological analysis and microscopic staging indicated that over the three year study, we collected sheepshead from all 6 gonadal stages. Further, two or more gonadal stages were evident in the same ovary at a given time, indicating that Chesapeake Bay sheepshead are batch spawners. In addition, when we combine all our microscopic staging data across month of capture, we see that we only collected spawning capable and actively spawning sheepshead in the months of May, June, and December (Figure 12). This data, combined with literature data that suggests sheepshead only spawn in other regions during the late-winter to spring months, suggests that the spawning season of Chesapeake Bay sheepshead is from December through June. We make this conclusion despite the fact that we were unable to collect any females from the months of January through April. However, the collection of YOY sheepshead from July through November in 2006 and 2007 supports our conclusion.

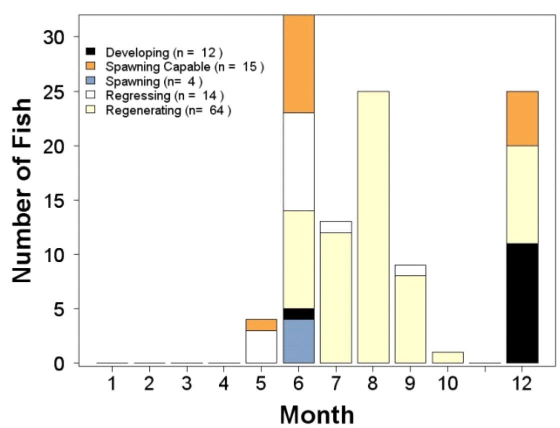


Figure 12. Frequency of microscopic maturity stages across months for Chesapeake Bay sheepshead collected between 2006 and 2008. The spawning season is identified as the period of time over which females are identified as having gonads in the spawning capable or actively spawning stage.

5. Mortality estimates

Total mortality (Z) – A standard catch-curve analysis was conducted on all fish collected via either the recreational or commercial fishery. When fish from these fisheries were analyzed, we observed peak numbers-at-age at 9 years old (n=36). However, as is common practice, we conducted the catch-curve analysis on sheepshead age 10+ years old because these were the age groups represented after peak numbers-at-age were observed. Because it is not known whether fish are fully recruited to gears at the age associated with peak numbers, you start your catch-curve analysis with the next oldest age group. Further, because of the presence of 0 fish collected in some age groups (age groups 27, 28, and 31), we added 1 to each age group before natural log transformation of the numbers-at-age for analysis.

From the catch-curve analysis (Figure 13), we get an estimated instantaneous mortality rate of 0.108 (± 0.0133). This converts to an annual survival rate of 89.8% (88.6-91.0%) for sheepshead aged 10 years and older in Chesapeake Bay. Conversely, the annual mortality rate was 10.2% (9.0-11.4%).

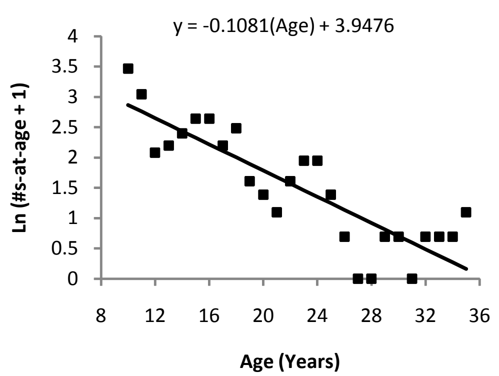


Figure 13. Catch-curve analysis for Chesapeake Bay sheepshead collected between 2006 and 2008.

Natural mortality - When estimating the natural mortality rate of Chesapeake Bay sheepshead, we calculated the natural mortality rate using a maximum age of 35 years old, which is the oldest age we have observed over the past three years of data collection. When we set t_{max} to 35, with the Hoenig method we obtain an estimate of M to be 0.129. Subsequently, when we implement the Q&D method for natural mortality rate estimation assuming either 1% or 5% of the population attains t_{max} we obtain an estimate of 0.132 or 0.086 for M, respectively. Thus, in the modeling used to determine biological reference points, natural mortality rates varying from 0.086 to 0.132 were investigated.

6. Yield per recruit and management options

The population parameters used in YPR modeling are: L_∞ = 21.7 in (550 mm), k = 0.288, t_0 = -0.855, and W_∞ = 4.545 kg (4545 g).

Under the fishing mortality of 0.086 - Our yield per recruit model indicated that the cohort lifetime maximum yield per recruit of 1.96 kg could be obtained at a catch age of 8 (about a fork length of 20 in.) with an infinite fishing mortality under the natural mortality of 0.086 (Figure 14 and Table 4). However, under F_{ABC} fishing mortality of 0.104, the maximum yield per recruit of 1.42 kg would be obtained at age 5, which is 72.4% of the cohort lifetime maximum yield per recruit (Table 4).

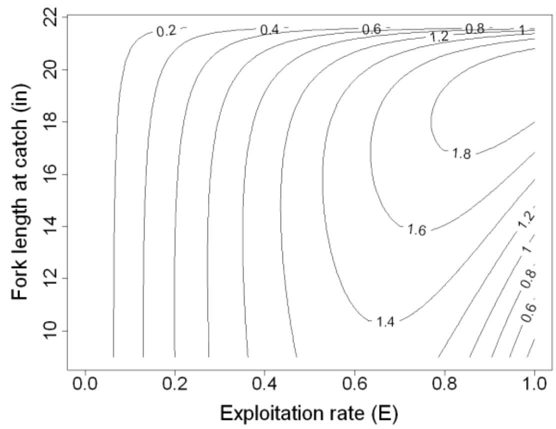


Figure 14. Yield per recruit for sheepshead in Chesapeake Bay, Virginia, with a natural mortality of 0.086.

Because 100% of sheepshead female matured at age 5 (about 18 in.) in Chesapeake Bay, we recommend that the minimum length limit should be 19 in, therefore, every fish would be allowed to reproduce at least once in its lifetime. At this length limit, Chesapeake Bay anglers will be able to harvest 72% of the cohort maximum yield per recruit, which is 0.4% less than the percentage of maximum yield that would be maximized under an 18 in minimum length limit (Table 4).

Trophy fish catch could be maximized up to 54 per 1000 recruits with the 19 in minimum length limit if the fishing mortality rate is managed at 0.055 (Table 5). However, under this scenario, the yield per recruit would decrease to 51.6% of the cohort lifetime maximum yield per recruit. Further, we found that a slot limit of 19-20 in. with a fishing mortality rate of 0.11 would not only maximize trophy fish catch (91 trophy fish caught per 1000 recruits) but also increase the yield per recruit achieved to 71.5% of the cohort lifetime maximum yield per recruit. This fishing mortality and yield per recruit are similar to the yield per recruit obtained using the minimum length limit without maximizing trophy catch (Tables 4 and 5).

Under the natural mortality of 0.132 - Our yield per recruit model indicated that the cohort lifetime maximum yield per recruit of 1.5 kg would be obtained at a catch age of 6 (about a fork length of 19 in.) with an infinite instantaneous fishing mortality rate (Figure 15 and Table 6). However, under F_{ABC} of 0.147, the maximum yield per recruit of 1.1 kg would be obtained at age 4, which is 73.4% of the cohort lifetime maximum yield per recruit (Table 6).

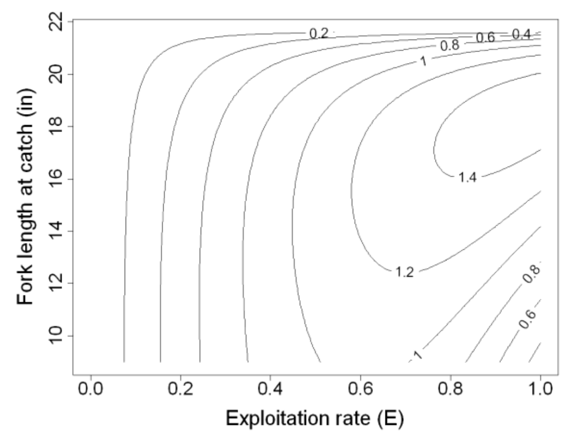


Figure 15. Yield per recruit for sheepshead in Chesapeake Bay, Virginia, with a natural mortality of 0.132.

Because 100% of sheepshead female matured by age 5 (about 18 in.) in Chesapeake Bay, we recommend that the minimum length limit should be 19 in, therefore, every fish would be allowed to reproduce at least once for its lifetime. The minimum length limit of 19 will allow the harvest of 70.4% of the cohort lifetime maximum yield per recruit, which is only 3% less than that harvested under an 18 in minimum length limit (Table 6).

To maximize trophy fish catch with a 19 in. minimum length limit, we would need to constrain the fishing mortality rate to 0.062. This would allow the harvest of 20 trophy fish from 1000 recruits (Table 7). However, at this low fishing mortality rate, the yield per recruit would decrease to 42% of the cohort lifetime maximum yield per recruit. Further, we found that a slot limit of 19-20 in. with a fishing mortality rate of 0.127 would not only maximize trophy fish catch (up to 36 trophy fish harvested per 1000 recruits) but also allow the harvest of 63% of the cohort lifetime maximum yield per recruit. Under the natural mortality of 0.132, maximizing trophy catch could reduce yield per recruit from 70.4% to 63% (Tables 6 and 7).

DISCUSSION

Murdy et al. (1997) reported that the sheepshead of Chesapeake Bay could live longer than 8 years, which is supported by our data, since we have found sheepshead that are up to 35 years old in the Bay, which is much older than expected previously. Further, our evidence suggests sheepshead of Chesapeake Bay are growing faster than those in southern states, are spawning between December and June, and that YOY sheepshead inhabit the bay from July through November. These significant differences in vital rates, along with the presence of spawning females and YOY, indicate that the sheepshead population of the Chesapeake Bay is a unique stock. Using the vital rates of the sheepshead of Chesapeake Bay, we estimated biological reference points and developed a preliminary management plan for the species. This plan attempted to provide both a maximum yield for the yield-based commercial fishery and trophy fish for the recreational fishery while preventing occurrence of overfishing (recruitment and growth overfishing), and it has been submitted to VMRC for consideration (Please contact the CQFE or the VMRC for details). Currently, we are continuing to examine the reproductive status of sheepshead in the Chesapeake Bay. We will develop a final management plan for sheepshead fisheries once the study is completed.

REFERENCES

Beckman, D. W., A. L. Stanley, J. H. Render, and C. A. Wilson. 1991. Age and growth-rate estimation of sheepshead *Archosargus probatocephalus* in Louisiana waters using otoliths. Fishery Bulletin 89(1):1-8.

Brown-Peterson et al. 2007. An improved and simplified terminology for reproductive classification in fishes. Presented at JMIH Conference, St. Louis, Missouri, July 2007.

Campana, S. E., M. C. Annand, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society 124(1):131-138.

Dutka-Gianelli, J., and D. J. Murie. 2001. Age and growth of sheepshead, Archosargus probatocephalus (Pisces : Sparidae), from the northwest coast of Florida. Bulletin of Marine Science 68(1):69-83.

Goodman D., M. Mangel, G. Parkes, T. Quinn, V. Restrepo, T. Smith, K. Stokes. 2002. Scientific review of the harvest strategy currently used in the BSAI and GOA groundfish fishery management plans. North Pacific Fishery Management Council Draft Report. 153p.

Helser, T. E. 1996. Growth of silver hake within the US continental shelf ecosystem of the northwest Atlantic Ocean. Journal of Fish Biology 48(6):1059-1073.

Hewitt, D. A. and J. M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longetivity. Fish. Bull. 103:433-437.

Hoenig, J. M. 1984. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82:898-903.

Hoenig, J. M., M. J. Morgan, and C. A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Canadian Journal of Fisheries and Aquatic Sciences 52:364-368.

Kimura, D. K. 1980. Likelihhod methods for the Von Bertalanffy growth curve. Fishery Bulletin 77(4):765-776.

.

MacDonald, T. C., B. L. Winner, and K. B. Amendola. In Review. Age and growth of sheepshead, *Archosargus probatocephalus*, from Tampa Bay, Florida. Fishery Bulletin.

Munyandorero, J., M. D. Murphy, and T. C. MacDonald. 2006. An Assessment of the Status of Sheepshead in Florida Waters through 2004. Pages 113 *in* M. R. Florida Fish and Wildlife Conservation Commission, editor, St. Petersburgh, Florida.

Murdy, E. O., R. S. Birdsong, and J. A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press, Washington and London.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Wenner, C. 1996. Age and Growth of Sheepshead, *Archosargus probatocephalus*, from South Carolina Waters with some

Preliminary Management Concepts. Pages 17 *in* S. C. D. o. N. Resources, editor, Charleston, South Carolina.

Zar, J. H. 1996. Biostatistical analysis, 3rd edition. Prentic-Hall, Upper Saddle River, New Jersey. 662 p.

Table 1. The number of sheepshead assigned to each total length (inch)-at-age category for 552 fish sampled for otolith age determination in Virginia during 2008. There are 5 fish aged without length.

Interval	Age										
	0	1	2	3	4	5	6	7	8	9	10
0-0.99	1	0	0	0	0	0	0	0	0	0	0
1-1.99	9	0	0	0	0	0	0	0	0	0	0
2-2.99	10	0	0	0	0	0	0	0	0	0	0
3-3.99	39	0	0	0	0	0	0	0	0	0	0
4-4.99	19	0	0	0	0	0	0	0	0	0	0
5-5.99	18	0	0	0	0	0	0	0	0	0	0
6-6.99	17	0	0	0	0	0	0	0	0	0	0
7-7.99	16	1	0	0	0	0	0	0	0	0	0
8-8.99	3	4	0	0	0	0	0	0	0	0	0
9-9.99	0	18	1	0	0	0	0	0	0	0	0
10-10.99	0	42	4	0	0	0	0	0	0	0	0
11-11.99	0	18	4	1	0	0	0	0	0	0	0
12-12.99	0	8	2	1	0	0	0	0	0	0	0
13-13.99	0	1	3	2	0	0	0	0	0	0	0
14-14.99	0	0	2	2	0	0	0	0	0	0	1
15-15.99	0	0	1	3	1	0	0	0	0	0	0
16-16.99	0	0	0	1	0	0	0	0	0	0	0
17-17.99	0	0	0	2	1	5	1	0	1	1	0
18-18.99	0	0	0	0	1	9	2	2	0	1	2
19-19.99	0	0	0	0	0	8	4	3	1	1	1
20-20.99	0	0	0	0	1	9	8	7	5	4	3
21-21.99	0	0	0	0	2	1	5	8	6	6	4
22-22.99	0	0	0	0	0	0	3	3	3	15	11
23-23.99	0	0	0	0	0	0	0	1	4	8	6
24-24.99	0	0	0	0	0	0	0	0	1	2	1
25-25.99	0	0	0	0	0	0	0	0	0	0	1
26-26.99	0	0	0	0	0	0	0	0	0	0	1
Totals	132	92	17	12	6	32	23	24	21	38	31

Table 1. (continued)

Interval	Age										
	11	12	13	14	15	16	17	18	19	20	21
0-0.99	0	0	0	0	0	0	0	0	0	0	0
1-1.99	0	0	0	0	0	0	0	0	0	0	0
2-2.99	0	0	0	0	0	0	0	0	0	0	0
3-3.99	0	0	0	0	0	0	0	0	0	0	0
4-4.99	0	0	0	0	0	0	0	0	0	0	0
5-5.99	0	0	0	0	0	0	0	0	0	0	0
6-6.99	0	0	0	0	0	0	0	0	0	0	0
7-7.99	0	0	0	0	0	0	0	0	0	0	0
8-8.99	0	0	0	0	0	0	0	0	0	0	0
9-9.99	0	0	0	0	0	0	0	0	0	0	0
10-10.99	0	0	0	0	0	0	0	0	0	0	0
11-11.99	0	0	0	0	0	0	0	0	0	0	0
12-12.99	0	0	0	0	0	0	0	0	0	0	0
13-13.99	0	0	0	0	0	0	0	0	0	0	0
14-14.99	0	0	0	0	0	0	0	0	0	0	0
15-15.99	0	0	0	0	0	0	0	0	0	0	0
16-16.99	0	0	0	0	0	0	0	0	0	0	0
17-17.99	0	0	0	0	0	0	0	0	0	0	0
18-18.99	0	1	0	0	0	0	0	0	0	0	0
19-19.99	0	0	0	0	0	0	0	0	0	0	0
20-20.99	1	1	1	0	0	0	0	0	0	0	0
21-21.99	1	0	2	2	0	0	0	1	0	0	0
22-22.99	4	3	0	2	2	5	3	2	1	0	0
23-23.99	4	2	3	1	5	5	1	4	1	0	0
24-24.99	7	0	2	5	4	2	2	3	0	2	2
25-25.99	2	0	0	0	2	1	2	1	2	1	1
26-26.99	0	0	0	0	0	0	0	0	0	0	0
Totals	19	7	8	10	13	13	8	11	4	3	3

Table 1. (continued)

Interval	Age										
	22	23	24	25	26	29	30	32	33	34	35	Totals
0-0.99	0	0	0	0	0	0	0	0	0	0	0	1
1-1.99	0	0	0	0	0	0	0	0	0	0	0	9
2-2.99	0	0	0	0	0	0	0	0	0	0	0	10
3-3.99	0	0	0	0	0	0	0	0	0	0	0	39
4-4.99	0	0	0	0	0	0	0	0	0	0	0	19
5-5.99	0	0	0	0	0	0	0	0	0	0	0	18
6-6.99	0	0	0	0	0	0	0	0	0	0	0	17
7-7.99	0	0	0	0	0	0	0	0	0	0	0	17
8-8.99	0	0	0	0	0	0	0	0	0	0	0	7
9-9.99	0	0	0	0	0	0	0	0	0	0	0	19
10-10.99	0	0	0	0	0	0	0	0	0	0	0	46
11-11.99	0	0	0	0	0	0	0	0	0	0	0	23
12-12.99	0	0	0	0	0	0	0	0	0	0	0	11
13-13.99	0	0	0	0	0	0	0	0	0	0	0	6
14-14.99	0	0	0	0	0	0	0	0	0	0	0	5
15-15.99	0	0	0	0	0	0	0	0	0	0	0	5
16-16.99	0	0	0	0	0	0	0	0	0	0	0	1
17-17.99	0	0	0	0	0	0	0	0	0	0	0	11
18-18.99	0	0	0	0	0	0	0	0	0	0	0	18
19-19.99	0	0	0	0	0	0	0	0	0	0	0	18
20-20.99	0	0	0	0	0	0	0	0	0	0	0	40
21-21.99	0	0	0	0	0	0	0	0	0	0	0	38
22-22.99	1	0	0	0	0	0	0	0	0	0	0	58
23-23.99	1	3	2	1	0	1	0	0	0	0	0	53
24-24.99	0	1	1	1	1	0	0	0	1	1	2	41
25-25.99	0	2	1	1	0	0	1	1	0	0	0	19
26-26.99	1	0	1	0	0	0	0	0	0	0	0	3
Totals	3	6	5	3	1	1	1	1	1	1	2	552

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for sheepshead sampled for age determination in Virginia during 2008.

Interval	Age										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0-0.99	1	0	0	0	0	0	0	0	0	0	0
1-1.99	1	0	0	0	0	0	0	0	0	0	0
2-2.99	1	0	0	0	0	0	0	0	0	0	0
3-3.99	1	0	0	0	0	0	0	0	0	0	0
4-4.99	1	0	0	0	0	0	0	0	0	0	0
5-5.99	1	0	0	0	0	0	0	0	0	0	0
6-6.99	1	0	0	0	0	0	0	0	0	0	0
7-7.99	0.941	0.059	0	0	0	0	0	0	0	0	0
8-8.99	0.429	0.571	0	0	0	0	0	0	0	0	0
9-9.99	0	0.947	0.053	0	0	0	0	0	0	0	0
10-10.99	0	0.913	0.087	0	0	0	0	0	0	0	0
11-11.99	0	0.783	0.174	0.043	0	0	0	0	0	0	0
12-12.99	0	0.727	0.182	0.091	0	0	0	0	0	0	0
13-13.99	0	0.167	0.5	0.333	0	0	0	0	0	0	0
14-14.99	0	0	0.4	0.4	0	0	0	0	0	0	0.2
15-15.99	0	0	0.2	0.6	0.2	0	0	0	0	0	0
16-16.99	0	0	0	1	0	0	0	0	0	0	0
17-17.99	0	0	0	0.182	0.091	0.455	0.091	0	0.091	0.091	0
18-18.99	0	0	0	0	0.056	0.5	0.111	0.111	0	0.056	0.111
19-19.99	0	0	0	0	0	0.444	0.222	0.167	0.056	0.056	0.056
20-20.99	0	0	0	0	0.025	0.225	0.2	0.175	0.125	0.1	0.075
21-21.99	0	0	0	0	0.053	0.026	0.132	0.211	0.158	0.158	0.105
22-22.99	0	0	0	0	0	0	0.052	0.052	0.052	0.259	0.19
23-23.99	0	0	0	0	0	0	0	0.019	0.075	0.151	0.113
24-24.99	0	0	0	0	0	0	0	0	0.024	0.049	0.024
25-25.99	0	0	0	0	0	0	0	0	0	0	0.053
26-26.99	0	0	0	0	0	0	0	0	0	0	0.333

Table 2. (continued)

Interval	Age

	11	12	13	14	15	16	17	18	19	20	21
0-0.99	0	0	0	0	0	0	0	0	0	0	0
1-1.99	0	0	0	0	0	0	0	0	0	0	0
2-2.99	0	0	0	0	0	0	0	0	0	0	0
3-3.99	0	0	0	0	0	0	0	0	0	0	0
4-4.99	0	0	0	0	0	0	0	0	0	0	0
5-5.99	0	0	0	0	0	0	0	0	0	0	0
6-6.99	0	0	0	0	0	0	0	0	0	0	0
7-7.99	0	0	0	0	0	0	0	0	0	0	0
8-8.99	0	0	0	0	0	0	0	0	0	0	0
9-9.99	0	0	0	0	0	0	0	0	0	0	0
10-10.99	0	0	0	0	0	0	0	0	0	0	0
11-11.99	0	0	0	0	0	0	0	0	0	0	0
12-12.99	0	0	0	0	0	0	0	0	0	0	0
13-13.99	0	0	0	0	0	0	0	0	0	0	0
14-14.99	0	0	0	0	0	0	0	0	0	0	0
15-15.99	0	0	0	0	0	0	0	0	0	0	0
16-16.99	0	0	0	0	0	0	0	0	0	0	0
17-17.99	0	0	0	0	0	0	0	0	0	0	0
18-18.99	0	0.056	0	0	0	0	0	0	0	0	0
19-19.99	0	0	0	0	0	0	0	0	0	0	0
20-20.99	0.025	0.025	0.025	0	0	0	0	0	0	0	0
21-21.99	0.026	0	0.053	0.053	0	0	0	0.026	0	0	0
22-22.99	0.069	0.052	0	0.034	0.034	0.086	0.052	0.034	0.017	0	0
23-23.99	0.075	0.038	0.057	0.019	0.094	0.094	0.019	0.075	0.019	0	0
24-24.99	0.171	0	0.049	0.122	0.098	0.049	0.049	0.073	0	0.049	0.049
25-25.99	0.105	0	0	0	0.105	0.053	0.105	0.053	0.105	0.053	0.053
26-26.99	0	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

Interval	Age										
	22	23	24	25	26	29	30	32	33	34	35
0-0.99	0	0	0	0	0	0	0	0	0	0	0
1-1.99	0	0	0	0	0	0	0	0	0	0	0
2-2.99	0	0	0	0	0	0	0	0	0	0	0
3-3.99	0	0	0	0	0	0	0	0	0	0	0
4-4.99	0	0	0	0	0	0	0	0	0	0	0
5-5.99	0	0	0	0	0	0	0	0	0	0	0
6-6.99	0	0	0	0	0	0	0	0	0	0	0
7-7.99	0	0	0	0	0	0	0	0	0	0	0
8-8.99	0	0	0	0	0	0	0	0	0	0	0
9-9.99	0	0	0	0	0	0	0	0	0	0	0
10-10.99	0	0	0	0	0	0	0	0	0	0	0
11-11.99	0	0	0	0	0	0	0	0	0	0	0
12-12.99	0	0	0	0	0	0	0	0	0	0	0
13-13.99	0	0	0	0	0	0	0	0	0	0	0
14-14.99	0	0	0	0	0	0	0	0	0	0	0
15-15.99	0	0	0	0	0	0	0	0	0	0	0
16-16.99	0	0	0	0	0	0	0	0	0	0	0
17-17.99	0	0	0	0	0	0	0	0	0	0	0
18-18.99	0	0	0	0	0	0	0	0	0	0	0
19-19.99	0	0	0	0	0	0	0	0	0	0	0
20-20.99	0	0	0	0	0	0	0	0	0	0	0
21-21.99	0	0	0	0	0	0	0	0	0	0	0
22-22.99	0.017	0	0	0	0	0	0	0	0	0	0
23-23.99	0.019	0.057	0.038	0.019	0	0.019	0	0	0	0	0
24-24.99	0	0.024	0.024	0.024	0.024	0	0	0	0.024	0.024	0.049
25-25.99	0	0.105	0.053	0.053	0	0	0.053	0.053	0	0	0
26-26.99	0.333	0	0.333	0	0	0	0	0	0	0	0

Table 3. Von Bertalanffy growth curve parameters, maximum fork lengths, maximum ages, and ageing validation studies reported for sheepshead (MI=marginal increment analysis and CL=chemical labeling using oxytetracycline and calcein).

Source	Location	Sex	L_∞	k	t_0	Max FL (mm)	Max Age (yrs)	Age Validation
Matlock (1992)[a]	Texas	Combined	437[b]	0.36	–	505[b]	–	–
Beckman et al. (1991)	Louisiana	Male	419	0.42	-0.90	505	20	MI
		Female	447	0.37	-1.03	560	20	MI
Dutka-Gianelli & Murie (2001)	Florida: Northwest	Combined	490	0.26	-0.42	522	14	MI, CL
Murphy & MacDonald (2000)	Florida: Gulf Coast	Combined	451	0.24	-1.17	–	13-16	–
MacDonald et al. (In Review)	Florida: Tampa Bay	Male	425	0.24	-1.32	452	14	MI
		Female	428	0.26	-1.11	399	13	MI
Tim MacDonald (pers. comm.)	Florida: Tampa Bay	Combined	441	0.22	-1.48	523	15	MI
Murphy & MacDonald (2000)	Florida: Atlantic Coast	Combined	381	0.39	-1.13	–	13-16	–
Tim MacDonald (pers. comm.)	Florida: Indian River Lagoon	Male	–	–	–	495	21	MI
		Female	–	–	–	491	17	MI
		Combined	381	0.33	-1.18	495	21	MI
Chris McDonough (pers. comm.)	South Carolina	Male	–	–	–	567	19	MI
		Female	–	–	–	603	23	MI
		Combined	498	0.30	-1.10	603	23	MI
Schwartz (1990)	North Carolina	Combined	–	–	–	657[b]	8	–
This Study	Chesapeake Bay	Male	537	0.31	-0.77	594	35	MI
		Female	556	0.28	-0.90	623	35	MI

[a]—Used mark-recapture version of von Bertalanffy growth model $L_r = L_m + (L_\infty - L_m) * (1 - e^{-kd})$ where L_r is total length at recapture, L_m is total length at marking, d is the number of days between mark and recapture, and L_∞ and k are defined as above.
[b]—Lengths originally reported as total length. Converted to fork length using the length-length regression in this report.

Table 4. Estimates of the maximum yield per recruit (kg) and their corresponding fishing mortality (F_{max}), and the yield per recruit and their corresponding fish mortality $F_{0.1}$ and F_{ABC} at a variety of catch age (t_c) under a natural mortality of 0.086. *E* is the exploitation rate corresponding to *F*. Y/R is the yield per recruit and Y*/R is the cohort lifetime maximum yield per recruit (1.96 kg) at age 8 (about 20 in. fork length).

Age at catch (t_c)	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**17**
Length at catch (L_c)	9	12	15	17	18	19	20	21	22
E_{max}	0.666	0.700	0.780	0.810	0.890	0.930	1	1	1
F_{max}	0.171	0.201	0.305	0.367	0.696	1.143	∞	∞	∞
Y/R at F_{max}	1.34	1.50	1.65	1.79	1.87	1.93	1.96	1.84	1.13
$E_{0.1}$	0.504	0.538	0.569	0.602	0.618	0.635	0.651	0.669	0.682
$F_{0.1}$	0.087	0.100	0.113	0.130	0.139	0.149	0.161	0.174	0.184
Y/R at $F_{0.1}$	1.25	1.37	1.46	1.54	1.56	1.55	1.49	1.32	0.78
% of Y^*/R	63.7	69.8	74.8	78.8	79.7	79.3	76.4	67.4	39.6
E_{ABC}	0.433	0.466	0.497	0.532	0.548	0.566	0.584	0.602	0.616
F_{ABC}	0.066	0.075	0.085	0.098	0.104	0.112	0.121	0.130	0.138
Y/R at F_{ABC}	1.14	1.25	1.33	1.40	1.42	1.41	1.36	1.20	0.70
% of Y^*/R	58.1	63.6	68.1	71.7	72.4	72.0	69.3	61.1	35.9

Table 5. Estimates of the maximum trophy catch (fork length => 22 in.), their corresponding non-trophy catch and fishing mortality (F_{trmax}) using a variety of minimum length limits (L_c) and slot limits under a natural mortality of 0.086. Y/R is the yield per recruit and Y*/R is the cohort lifetime maximum yield per recruit (1.96 kg) at age 8 (about 20 in. fork length).

Age at catch (t_c)	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**17**
Length at catch (L_c)	**9**	**12**	**15**	**17**	**18**	**19**	**20**	**21**	**22**
					Minimum length limit				
F_{trmax}	0.042	0.044	0.046	0.049	0.052	0.055	0.064	0.076	-
Non trophy catch	286	266	247	232	216	200	173	147	-
Trophy catch	42	44	46	48	51	54	61	70	-
Total catch	328	310	293	280	267	254	234	217	-
Y/R	0.93	0.97	1.00	1.01	1.02	1.01	1.10	1.05	-
% of Y^*/R	47.2	49.4	51.0	51.4	51.9	51.6	56.1	53.7	-
					Slot limit				
F_{trmax}	0.064	0.069	0.076	0.084	0.095	0.110	0.169	-	-
Non trophy catch	315	291	268	245	222	198	145	-	-
Trophy catch	61	65	70	75	82	91	119	-	-
Total catch	376	356	337	320	304	289	264	-	-
Y/R	1.13	1.21	1.27	1.32	1.37	1.4	1.48	-	-
% of Y^*/R	57.4	61.5	65.0	67.5	69.8	71.5	75.4	-	-

Table 6. Estimates of the maximum yield per recruit (kg) and their corresponding fishing mortality (F_{max}) and the yield per recruit and their corresponding fish mortality $F_{0.1}$ and F_{ABC} at a variety of catch age (t_c) under a natural mortality of 0.132. E is the exploitation rate corresponding to F. Y/R is yield per recruit and Y*/R is the cohort lifetime maximum yield per recruit (1.50 kg) at age 6 (about 19 in. fork length).

Age at catch (t_c)	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**17**
Length at catch (L_c)	9	12	15	17	18	19	20	21	22
E_{max}	0.614	0.690	0.780	0.890	0.930	1	1	1	1
F_{max}	0.210	0.294	0.468	1.068	1.754	∞	∞	∞	∞
Y/R at F_{max}	1.04	1.19	1.32	1.44	1.48	1.50	1.44	1.21	0.54
$E_{0.1}$	0.475	0.517	0.555	0.597	0.615	0.634	0.652	0.667	0.682
$F_{0.1}$	0.119	0.142	0.165	0.195	0.211	0.228	0.247	0.264	0.282
Y/R at $F_{0.1}$	0.97	1.08	1.16	1.21	1.20	1.16	1.06	0.86	0.37
% of Y^*/R	64.5	71.9	77.5	80.7	80.3	77.5	70.7	57.0	24.7
E_{ABC}	0.404	0.446	0.483	0.526	0.545	0.565	0.584	0.600	0.616
F_{ABC}	0.090	0.106	0.124	0.147	0.158	0.171	0.186	0.198	0.212
Y/R at F_{ABC}	0.88	0.98	1.06	1.10	1.09	1.06	0.96	0.77	0.34
% of Y^*/R	58.8	65.6	70.5	73.4	73.0	70.4	64.1	51.6	22.4

Table 7. Estimates of the maximum trophy catch (fork length => 22 in.), their corresponding non-trophy catch and fishing mortality (F_{trmax}) using a variety of minimum length limits (L_c) and slot limits under a natural mortality of 0.132. Y/R is yield per recruit and Y*/R is the cohort lifetime maximum yield per recruit (1.50 kg) at age 6 (about 19 in. fork length).

Age at catch (t_c)	1	2	3	4	5	6	8	10	17
Length at catch (L_c)	**9**	**12**	**15**	**17**	**18**	**19**	**20**	**21**	**22**
Minimum length limit									
F_{trmax}	0.046	0.049	0.051	0.054	0.058	0.062	0.072	0.086	-
Non trophy catch	243	222	198	178	162	146	118	94	-
Trophy catch	15	16	17	17	18	20	22	26	-
Total catch	258	238	215	195	180	166	140	120	-
Y/R	0.63	0.66	0.67	0.65	0.66	0.63	0.58	0.52	-
% of Y^*/R	42	44	45	44	44	42	38	35	-
Slot limit									
F_{trmax}	0.072	0.078	0.086	0.096	0.109	0.127	0.199	-	-
Non trophy catch	296	266	238	212	187	164	116	-	-
Trophy catch	22	24	26	29	32	36	49	-	-
Total catch	319	290	264	240	219	199	165	-	-
Y/R	0.80	0.86	0.91	0.91	0.94	0.95	0.96	-	-
% of Y^*/R	54	58	60	61	63	63	64	-	-